HYDROKINETIC ENERGY FOR ENLIGHTENING THE FUTURE OF RURAL COMMUNITIES IN UTTARAKHAND

Udit Tewari
Senior Engineer, THDC India Limited
Koteshwar, India

Karl Kolmsee
Managing Director, Smart Hydro Power GmbH
Feldafing, Germany

David Norta
PhD Student, University of Luxembourg
Luxembourg City, Luxembourg.
RWTH Aachen University, Germany

ABSTRACT

Uttarakhand is a northern state of India located in the foothills of the Himalayan mountain ranges. It is rich in water resources with many perennial rivers originating in the state and has enormous potential for hydropower generation. Despite of this fact the recent floods and agitation on setting up large and small hydropower plants has put a question mark on the future hydropower development and thus future of rural electrification in the state. In this context, the paper presents an idea of using hydrokinetic energy as a viable solution for securing low impact and viable power for rural communities in Uttarakhand.

INTRODUCTION

State Uttarakhand geographically comprises of 13 districts with 8 districts completely in hilly region and is home to many perennial rivers with major rivers like Ganga, Yamuna, Bhagirathi and Alaknanda. Figure 1 shows the geographical profile of the state showing the physical altitude difference as one move across the state. Of the total population of the state, around 69.77 % live in rural areas [1] and suffers from inadequate supply of electricity resulting from difficult mountainous terrain and sparse population. Thus, in recent years a strong push for hydropower development has been made to harness the power of rivers in the state which has resulted in development of many large and small hydropower projects in the state. However, due to low capital investment in construction, operational and maintenance cost and shorter gestation period, the main emphasis on small hydropower development has been given in the state as it has been a viable alternative to supply energy needs of rural communities in the state.

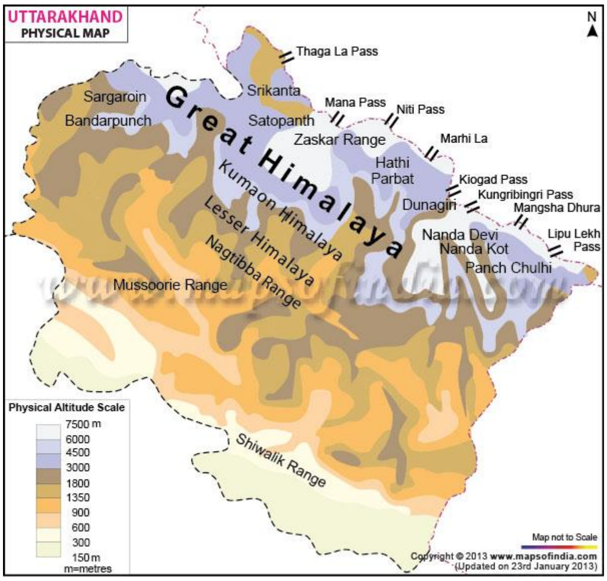

Figure 1: Geographic Profile of the State [2]

Small hydropower or SHP in India refers to a hydropower plant with a generating capacity less than 25 MW. The estimated potential in the country for such plants is about 20,000 MW [3] out of which the state Uttarakhand itself has an estimated capacity of about 3000 MW [4]. This high potential supplemented by favorable policy instruments and high rate of returns has thus resulted in the growth of SHP in the state. But floods in June 2013 overwhelmed the scores of setting up such hydropower plants. The flood seriously damaged at least 10 large hydro projects in operation and under construction. Another 19 small hydro power projects that generate under 25 MW were destroyed [5]. Though the disaster seemed to be an act of God, much of the blame was laid on the new hydropower infrastructure, which included nearly 100 hydropower projects, many of them smaller than 25 MW in capacity. A report commissioned by Indian Supreme Court said that the large and small hydropower plants in the state were responsible as they changed the river courses and flow of sedimentation, thus exacerbating the flood and environmental degradation of the state. This situation has resulted in uncertain future of hydropower development in the state which has impacted the future of rural electrification in the state. Therefore, the new and advanced technology of hydrokinetic energy for untapping the clean energy found in waterways can be the best potential way to secure reliable power in rural areas.

HYDROKINETIC ENERGY TECHNOLOGY

Hydrokinetic energy is the energy possessed by moving water. Producing power from the speed of water is what distinguishes hydrokinetic energy from conventional hydropower plants. Conventional hydropower plants use hydrostatic energy (potential energy) by impoundment of water behind dams for creating a hydraulic head and generating power, whereas the hydrokinetic turbine is powered by kinetic energy of the moving water, and is therefore also known as “zero head” or “in-stream” turbine. As such, no dams and/or head differential are necessary for the operation of this device; the course of a river remains in its natural state and no high investments in infrastructure are required. It can operate in base load fashion and deliver energy as long as the water keeps flowing. In this way it is a continuous renewable power source.

Principle of operation

Hydrokinetic turbines operate on the same principle as wind turbines and share similar design philosophies. The most notable difference is that the density of water is 850 times greater than air density. So the energy in the given flow of stream is much greater for a hydrokinetic turbine than for a wind turbine. Theoretical power extraction from a hydrokinetic turbine is given by:

$$P=0.5\ \rho\ A\ v^3 \qquad (1.1)$$

Where P= Power

ρ= density of water (kg/m^3)

A= blade swept area (m^2)

V= velocity of water (m/s)

Hydrokinetic turbines only capture a fraction of the kinetic energy in water that can pass through its cross section so maximum power extraction of 59% occurs when the downstream velocity is one-third of the upstream approach velocity. This value of 0.59 is the so called Betz limit for power extraction from flowing water and is the theoretical maximum coefficient of power Cp; the goal for the turbine design is to reach this limit. Therefore, a constant Cp is also included in the equation (1.1). Additionally, the conversion efficiency from mechanical energy to electrical energy depends on factors, such as blade shaping, bearing and AC-DC-AC converter, which typically have an efficiency of about 0.9. So the equation (1.1) has to be multiplied with these additional coefficients for deriving the maximum electrical energy that can be extracted from a hydrokinetic turbine. The resulting equation including all these coefficients is therefore [6]:

$$P=0.5\ \rho\ A\ v^3\ Cp\ \%E \qquad (1.2)$$

Where Cp= the Betz limit (maximum theoretical value 0.59)

%E= Efficiency of blade shaping, bearing and AC-DC-AC converter

The rotation speed of hydrokinetic turbine varies depending upon the rotor diameter and current speeds. Since the speed is variable, it is difficult to maintain a constant frequency. Therefore, a variable AC/DC/AC converter is used to accommodate variability due to varying current speeds and to maintain a desired constant frequency.

SMART HYDRO POWER TURBINE AND ITS OPERATION

The Smart Hydro Power turbine was developed to produce a maximum amount of electrical power with the kinetic energy of flowing waters. Because the amount of kinetic energy (velocity) varies from river to river, the capacity of the turbine ranges from a minimum of a few watts to a maximum of 5kW.

Turbine

The turbine (Figure 2) consists of a three bladed rotor, a 5 kW generator and a floating body consisting of a three piece diffuser and float. The three rotor blades are designed so that harmonious operation occurs underneath the surface of the water. Furthermore, the rotor blades consist of a fiber glass-reinforced epoxy so if they happen to break, an easy and affordable on-site replacement is made possible because of the simple design.

The core of the turbine lays a horizontal-axis, permanent magnet underwater generator. It is a slow turning generator which is there in order to increase fish friendliness and also so that no suction arises in front of the turbine.

The diffuser and float are part of the floating body of the turbine which adapts optimally to varying water conditions. The diffuser has two main functions; the first increases water pressure on the rotor and minimizes turbulences within the diffuser which therefore produces a maximum output, the latter provides the generator with its stable swimming position in water.

The turbine allows for various kinds of installations which depend on the specific demand and can also be simply integrated to other energy sources such as Photovoltaic and Wind. For floating installations, different types of anchor systems are used which always depend on the local river characteristics and conditions. Table 1 gives a brief summary of the technical specifications of hydrokinetic turbine.

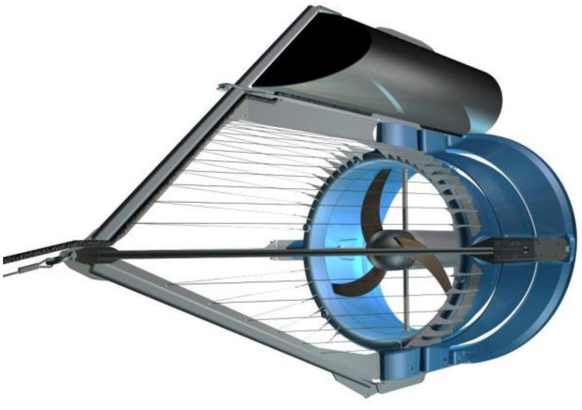

Figure 2: Smart Hydro Power Monofloat Hydrokinetic Turbine

Output	250-5000 W
Dimensions	Length: 3130 mm Width: 1600 mm Height: 2010 mm
Rotational Speed	90-230 rpm
Weight	380 kg
Number of Rotor Blades	3
Rotor Diameter	1000 mm

Table 1: Technical Specifications of Hydrokinetic Turbine

Electrical System

The turbine output is connected to an Electrical System that produces a stable single phase AC output at a given voltage and frequency. Figure 3 shows the Electrical System connected the output of the turbine. This is either synchronized to an existing grid in the case of grid connected model, or adjusted to match the requirements of each customer for an off-grid connected model. It also manages power between user, battery storage or optional auxiliary load and dump load.

Dump load is an electrical load used for safe and proper operation of hydrokinetic turbine system. For instance if a turbine operates under high water velocity or at no load, the turbine blades can spin so fast that the blades can come ripping off or, at the very least, put intense stresses and strains on the turbine components which will cause them to wear out very quickly. So a turbine is always kept under a constant load known as Dump load.

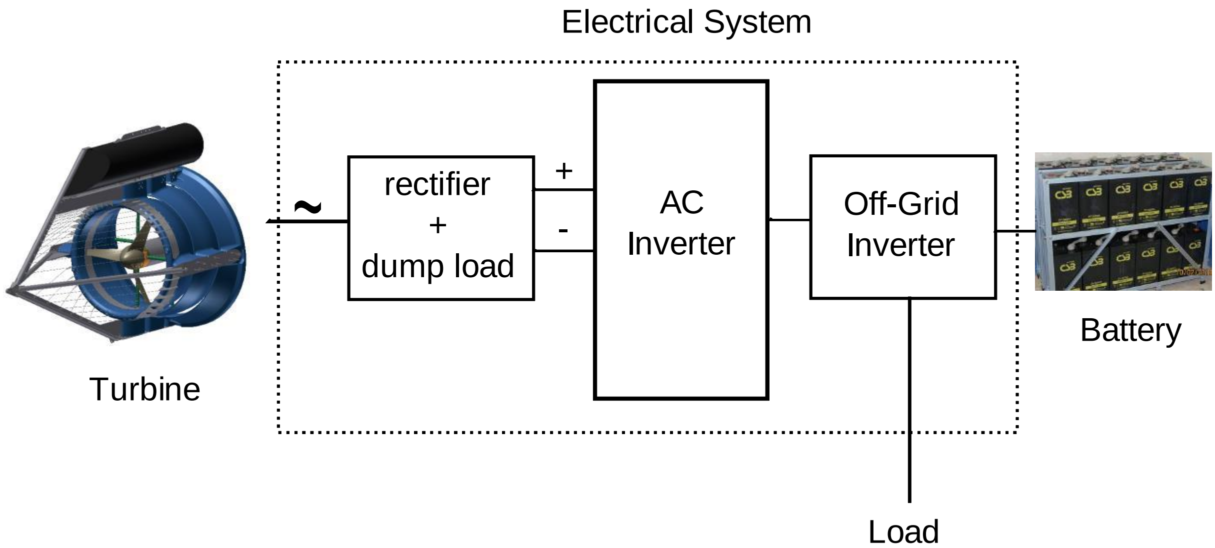

Figure 3: Electrical System connected the output of the turbine

River Characteristics Required

The power output of the turbine depends on the water velocity of a river or canal. Figure 4 shows the operating curve of the Smart Hydro Power Monofloat hydrokinetic turbine. The cut-in speed of the turbine i.e. the speed at which the turbine starts supplying useful power is 0.7 m/s. But the threshold velocity is usually 1.5 m/s were the turbine output is 1 kW output and is considered economically rational. The turbine produces maximum power output of 5 kW at river velocity of 2.8 m/s.

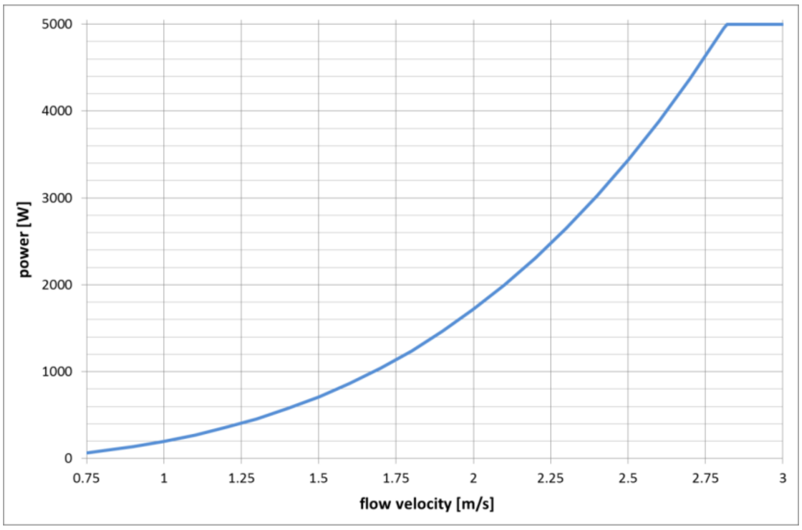

Figure 4: Operating curve of SMART Monofloat Kinetic Micro Hydro Generator

The river characteristics for the safe and efficient operation of the Smart Hydro turbine following data should be considered:

1. River flow rate for maximum power output of 5 kW: 2.8 m/s
2. Minimum river flow: 1.5 m/s
3. Maximum river flow: 3.5 m/s
4. Minimum river depth: 1.8 m
5. Minimum width: 2 m
6. Maximum recommended installation depth of generator: 10 m

The turbine has been analyzed for different kinds of rivers and thereupon optimized so that it can work in many situations. As there is no need for damming, no significant modifications to the natural river environment arise. It produces less than 70 % flow rate decrease as compared to conventional hydropower plants.

POSSIBLE SITES FOR SUCH INSTALLATION IN UTTARAKHAND

The Upper Ganga Segment from Gangotri to Rishikesh could be a best possible site for harnessing hydrokinetic energy using these turbines in Uttarakhand. This region is situated in high mountains with elevations ranging from 3000 m to 350 m above sea level. The region has a steep gradient, in order of 15 m per 1 km and has high velocities which present an ideal condition for deploying hydrokinetic turbines in this region. The main features of this region are summarized in Table 2 [7]. Figure 5 shows the map of the Upper Ganga Segment region with names of major places in the state.

Gaumukh to Haridwar	Details
Length (km)	240
Elevation (m)	3000 to 350
Slope (m/km)	15
Channel Width (m)	50 m to 250 m
Major Tributaries	Nauar, Mandakini, Alaknanda, Bhilangana, Pinder, Nandakini, Dhaliganga

Table 2: Summary of Main features of Upper Ganga Segment

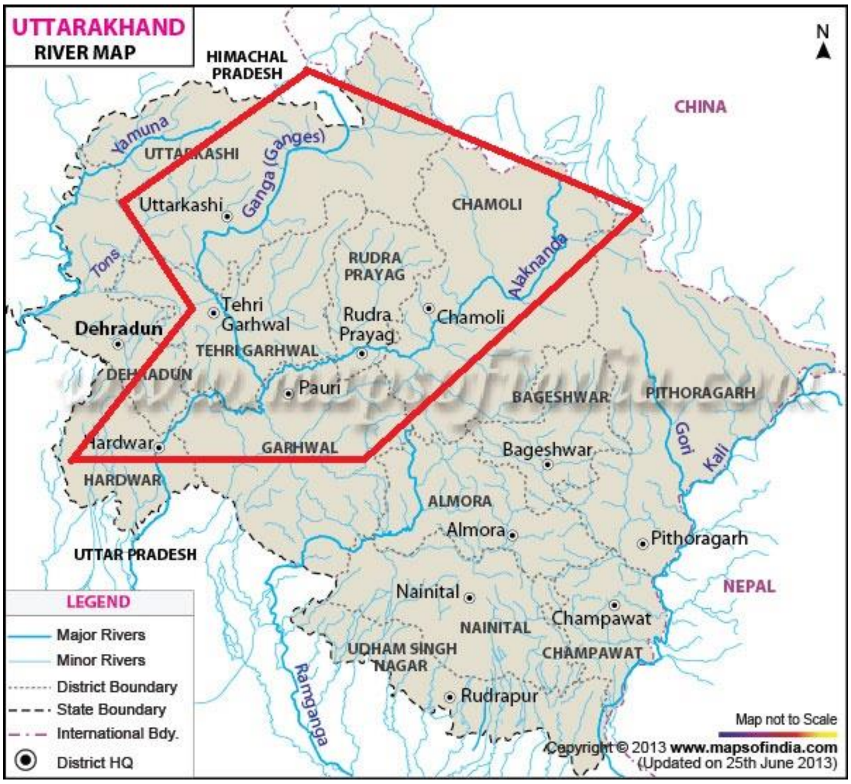

Figure 5: Map of the region for possible installation [8]

With the adequate data of the river characteristics the exact potential can be determined. Because the Ganga is a trans-boundary river, the historical measured flow data are classified, and are thus not available in public domain so only an approximate maximum theoretical potential can be determined.

Approximate Maximum Theoretical Potential of Hydrokinetic Energy in the Upper Ganga Segment

The hydrokinetic turbine introduced in this paper requires an approximate swept clearance of 50 m between two turbines so as to stabilize the river velocity entering the input of the other turbine.

Considering an ideal scenario such that the channel has high river velocities with an average channel width of 100 m and each turbine generates a maximum power output of 5 kW, the maximum number of turbines that can be installed will be 20 turbines per kilometer giving an approximate maximum power output of 0.1 MW per kilometer. With this approximation of the Upper Ganga Segment, the approximate theoretical potential of hydrokinetic energy for the length of 240 km comes to be around 24 MW.

The approximate theoretical potential derived here though does not examine the specific details and may vary from the exact potential. It only gives a rough estimate of the hydrokinetic potential available in the Upper Ganga Segment. In order to determine the exact potential it would require more in-depth study of the terrain and available water bodies, rural households located nearby and their average daily power requirements.

HYDROKINETIC ENERGY USE AS AN OFF-GRID SYSTEM

The hydrokinetic turbines discussed in this paper are capable of operating in both grid-connected and off-grid mode independently from the central grid. But as these are capable of generating low power output i.e. 0.1 MW per kilometer as computed earlier for the scenario considered, the cost of transmitting this power and connecting it to the central grid would be expensive. Considering a distribution line with resistance 0.2733 Ω per km (Dog conductor) the average power loss per km is around 2.58 % per km of the total power generated. Also distribution grid extension in a hilly remote terrain is difficult and costly. These factors therefore limit their use as an off-grid system and could only supply reliable and cost-efficient power to the rural community located in the vicinity of 1 km radius.

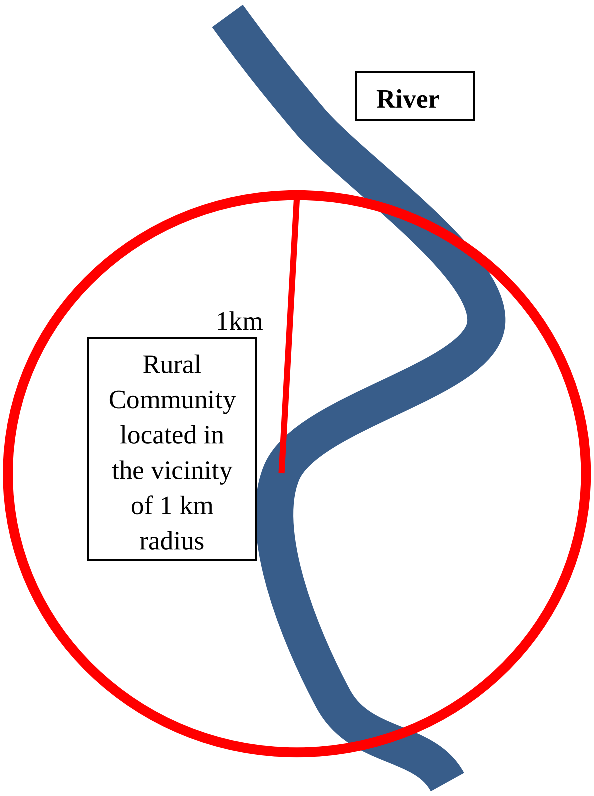

Figure 6: Generated power supply constraint

Using this constraint the maximum peak power that can be generated considering an ideal scenario with such turbines installed 1 km upstream and 1 km downstream where the rural community is located will be 200 kW. It is capable of supplying peak power demand of 200 households with 1 kWh peak power demand per household situated nearby.

However, the local demand for hilly remote areas due to small communities is usually lower than the viable threshold available. Also the turbine output will vary due to changing river velocity throughout the year so in order to stabilize the generated power and demand fluctuations a hybrid system can be used as an alternative. Such a system not only allows stabilizing load fluctuations during low demand in the local grid but also in the event of low power output from the turbines due to changing river velocities.

Hybrid System

A hybrid system combines photovoltaic and hydrokinetic energy and can work for different load profiles. Here hydrokinetic energy delivers the base load power for residential usage whereas photovoltaic meets the peak power demand required for other activities. Figure 7 shows the generated power curve per day for a year of such an installed hybrid system installed by Smart Hydro Power GmbH consisting of a 5 kW smart hydrokinetic turbine and a 1.6 kW peak photovoltaic panel. The result shows that the rain and sun are complementary during the year which tends to make the system 100 % available throughout the year.

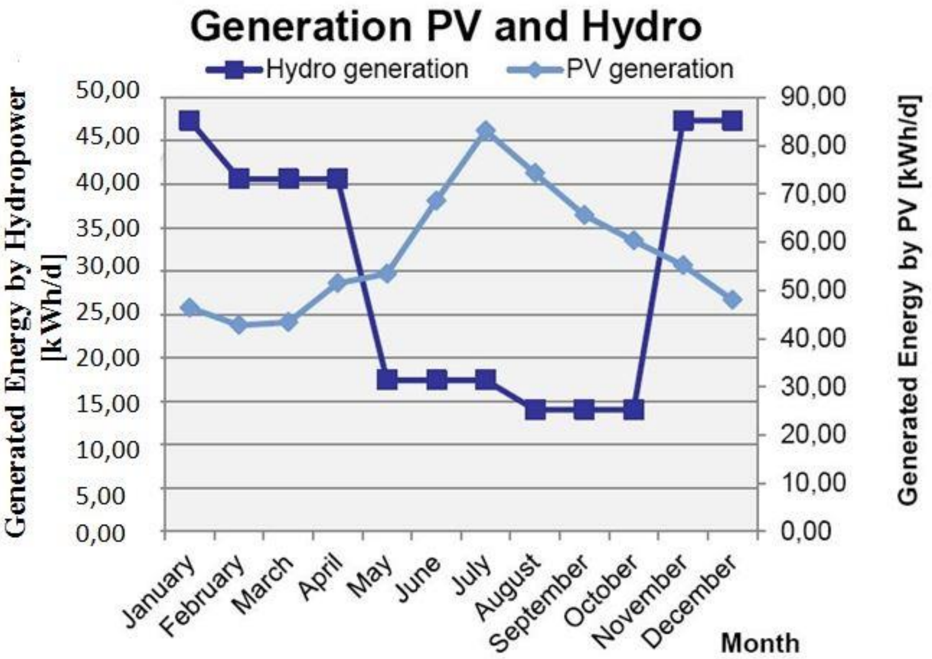

Figure 7: Yearly generation through a Hydrokinetic and Photovoltaic hybrid system

The hybrid system thus minimizes the need for battery storage compared with photovoltaic only system. The excess power generated in such system at low load demand times is stored in batteries for future use or can be used to power other auxiliary devices such water purifiers, water pump, water heaters etc. Using such hybrid systems for powering auxiliary systems and using excess power generated can help to build rural infrastructure.

The cost per kWh of such a hybrid system consisting of a 5 kW hydro and 1.6 kW photovoltaic is around € 0.016 per kWh or ₹ 1.14 per kWh (Conversion factor 1 € = ₹ 71.48) with an expected life of 20 years and 8500 hours operating hours per year considering an average stop time of 45 min per day. The cost per kWh thus makes it cost competitive with current rural electricity tariff in the state which is ₹ 1.50 per kWh for metered and ₹ 120 per connection for unmetered connection. Therefore, such hybrid systems can be installed across Upper Ganga segment for rural electrification and for developing rural infrastructure around villages situated nearby.

BENEFITS FROM HYDROKINETIC HYBRID SYSTEM TO RURAL COMMUNITIES IN UTTARAKHAND

The key feature of hybrid system is that they are able to operate independently of the central grid. This can help to improve the power quality and reliability, as well as allow the rural community to use excess power for community development. The implementation of such systems for providing electricity will benefit the rural communities in Uttarakhand in many ways such as:

1. Effective socio-political awareness
2. Improved infrastructural development schemes
3. Reduced rural-urban drift
4. Information technology at the doorstep of people
5. Reduction in environmental problems

In general, this technology will provide efficient and reliable access to energy for the rural population compared to the conventional energy sources that worked for the other regions of the state but might not be effective in the rural areas of Uttarakhand due to the associated difficult terrain.

CONCLUSION

Hydrokinetic turbine technology and possible site for its installation is presented in this paper. An idea of integration of photovoltaic to form a hybrid system is also given that makes the system more flexible and reliable.

The new hydropower technology of harnessing hydrokinetic potential in rivers by hydrokinetic turbines could be a possible way to cater to the energy need of the rural communities in Uttarakhand. Also with growing agitation and reluctance of the government in setting up conventional hydropower plants this technology has several advantages compared to other renewable technologies for water rich areas i.e. no impoundment. The future work intends to identify the exact potential of hydrokinetic power in Uttarakhand with detailed study of river characteristics in Upper Ganga Basin and develop a hybrid system model for this region.

REFERENCES

[1] Govt. of Uttarakhand. Department of School Education. [Online]. http://www.schooleducation.uk.gov.in
[2] Maps of India. Uttarakhand Physical Map. [Online]. http://www.mapsofindia.com/maps/uttaranchal
[3] Government of India. Ministry of New & Renewable Energy. [Online]. http://mnre.gov.in
[4] A Govt. of Uttarakhand Enterprise. UJVN Limited. [Online]. http://www.uttarakhandjalvidyut.com
[5] Keith Schneider. Circle of Blue. [Online]. http://www.circleofblue.org/waternews/2014/world
[6] G. E. Hecker, P. and G. Allen, "How to Evaluate Hydrokinetic Turbine Performance and Loads," PE Alden Research Laboratory.
[7] Nitin Kaushal, Luna Bharati, Vladimir Smakhtin Jay O'Keeffe, "Assessment of Environmental Flows for the Upper Ganga Basin," WWF-India, New Delhi, Study 2012.
[8] Maps of India. Uttarakhand River Map. [Online]. http://www.mapsofindia.com/maps/uttaranchal

Curriculum Vita

Udit Tewari obtained his Master of Science degree in Energy Systems from University of Applied Sciences Aachen in October 2014. He has worked as Student Intern in the field of hydrokinetics and distributed generation with Smart Hydro Power GmbH, Feldafing, Germany and University of Luxembourg during his master studies. He is currently working as Senior Engineer (Electrical) at Koteshwar Hydro Electric Project, THDC India Limited, India, where he is responsible for operation of hydro generators as per the requirement of the grid. His research interests include Hydrokinetics, grid integration of renewable energy resources and Energy Management.

Karl Kolmsee studied agricultural and philosophy at the universities of Hamburg and Goettingen, Germany. After his PhD he worked as a consultant at A.T. Kearney later as manager at E.ON, and later was member of the board at Schmack biogas. He is founder and managing director of Smart Utilities Solutions an international engineering office for decentralized energy and water solutions. In 2010 he founded Smart Hydro Power to focus on design and commercialization of kinetic pico hydro power systems. His main areas of interest are international energy markets and renewable energy.

David Norta obtained his Mechanical Engineering diploma in the field of turbulent flows analysis from the Technical University of Aachen in November 2012. He already worked in several international energy projects in India and Fiji in the frame of Engineers without Borders Germany and started Engineers without Borders Luxembourg. His PhD thesis title is, "Integration of distributed controllable renewable generators in the Luxembourgish electricity system including innovative micro-hydrokinetic turbines". David's interests of research area are renewable energies, micro-hydrokinetic turbines and smart grids.