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Automation and Wireless Communication in Micro Hydro Electric Plants: A Comprehensive Review

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ABSTRACT: Micro hydro electric plant (MHEP) is a good alternative instead of conventional electricity generation system for small-time entrepreneurs as the energy pay-back time and greenhouse gas emissions are relatively less than the conventional ones. The MHEP is a classic example of a mechatronic equipment which is an integration of electronics, computers, electrical, mechanical, instrumentation and civil engineering that make the living of the remote communities, livable and comfortable. However, it can be more sustainable if the operation of the MHEP is optimized through automation and wireless interventions. This review paper is an attempt of the various researches both experimental and actual actions that have taken place in this direction.

KEYWORDS: MHEP, automation, PLC, IoT, wireless, optimisation

I. INTRODUCTION

The Micro hydroelectric plants (MHEPs) are generally owned by small time entrepreneurs that are often run semi-automatically and are not optimized for sustainable operation due to sustainable technical constraints. Although sophisticated technologies are used in large hydro plants, not much relevant technology is available that can be directly used in MHEPs to render them techno-economically sustainable. Presently, digital technologies have opened up a wide array of opportunities to such small-time entrepreneurs to operate and maintain MHEPs sustainably. It is observed in the literature survey undertaken that there is a lack of sufficient information regarding optimization of MHEPs with Crossflow hydro-turbines mounted with squirrel cage induction generators, especially that are directly grid connected. Hence, this research is proposed to be undertaken for optimizations of MHEPs especially with regard to electronics and telecommunication engineering. Hence, 'integration of automated wireless control technologies for enhanced sustainability of the MHEPs will be quite beneficial' [Albita, 2023]. This paper suggests the extent of automation and wireless interventions that could be undertaken to optimize the working of micro-hydro plants.

II. MICRO HYDRO ELECTRIC PLANTS OVERVIEW

There are number of hydro plants and even various combinations of micro hydro electric plants due to which it is difficult to find 'one-solution-fits-for-all' strategies for each type of MHEP.

A. *Different Types of MHEPs:*

Aim of the proposed algorithm is to maximize the network life by minimizing the total transmission energy using energy efficient routes to transmit the packet. The proposed algorithm is consists of three main steps

- Pico-hydro-electric plants: producing <5 kW
- Micro-hydro-electric plants (MHEP): producing 5-100 kW
- Mini-hydro-electric plant: producing 100 kW-1000 kW
- Small-hydro-electric plants: producing 1000 kW-10,000 kW.

B. *MHEP and Their Various Components*

The MHEP is a classic example of a mechatronic equipment which is an integration of electronics, computers, electrical, mechanical, instrumentation and civil engineering that make the living of the remote communities, livable and comfortable. It broadly consists of a hydro turbine [Kumar, February, 2022] depending on the 'head' and other factors connected to an electrical generator by belt-pulley [ac-tec.it, W2] arrangement (see figure 1), a gearbox or a combination of both.

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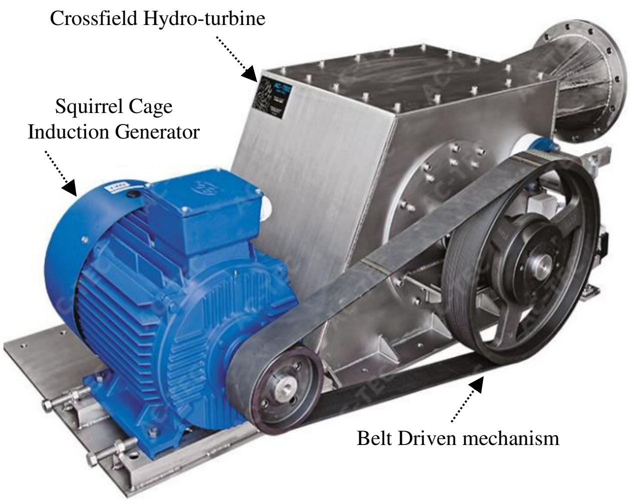

Figure 1. Micro Hydro Belt Driven Crossflow Hydro Turbine with Induction Generator
Courtesy: http://www.ac-tec.it/index_en.html

'A cross-flow turbine is drum-shaped and uses an elongated, rectangular section nozzle directed against curved vanes on a cylindrically shaped runner' [Achebe, July 2020]. Since it has a low price and good regulation, it is generally opted by small-time MHEP entrepreneurs. A typical panel board of the MHEP consists of two sections (see figure 2) clearly separated from each other: electronics and electrical. The electronic section consists of various relays and other electronic components. The electrical section holds high current and voltage components such as the current transformers (CTs), voltage transformers (VTs) and others.

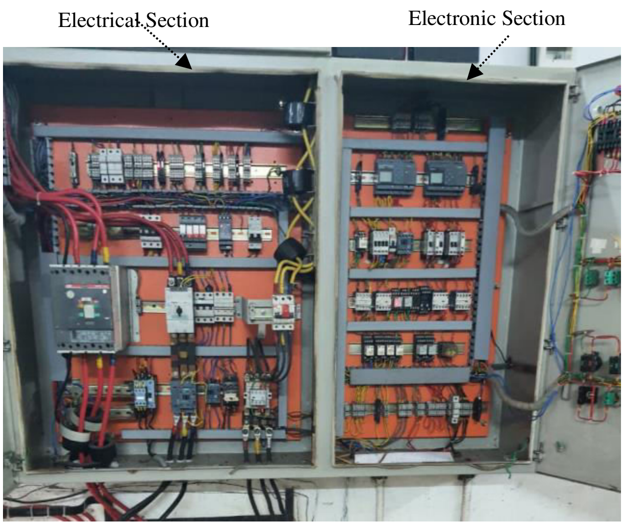

Figure 2 Typical Remote Located MHEP Panel Board

III. MHEP WITH INDUCTION GENERATOR

Induction generators have long been used in wind turbines. 'The induction generators used in MHEPs are of three types: Self-Excited Induction Generator, Doubly-Fed Induction Generator and Permanent Magnet Induction Generator' [Singh, 1993]. 'The squirrel cage induction generators are also used in small hydro power plants' [Rathore, June 2022]. When an induction machine runs as an induction motor, the rotor speed is slightly less than the synchronous speed of the machine. Whereas, when the rotor speed is slightly more than the synchronous speed of the induction machine, it becomes an induction generator. In MHEP operations, the hydro turbine acts as a prime mover to make the induction machine to run beyond synchronous speed and run as an induction generator supplying electric power directly to the electric grid.

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'Induction generators are approximately 75-95% efficient at full-load and efficiency can drop to 65-85% at partial-load' [Media, May 2016]. Singh, [2006] discusses 'the voltage and frequency controller (VFC) for isolated wound rotor induction generator for constant power applications such as pico-hydro uncontrolled turbines, simulated using MATLAB along with Simulink and PSB (power system block set) toolboxes. The simulated results are presented to demonstrate the capability of asynchronous generator system with VF controller for feeding 3-phase 4-wire loads'.

In a grid-connected system, the MHEPs mounted with induction generators up to 50 kW work well especially in grid connected systems. Induction generators are preferred because such MHEPs are simpler in synchronizing especially with strong grids. Moreover, they are more robust and requires lesser maintenance.

IV. Challenges In Optimizing MHEP

In conventional MHEPs, costs can increase and operations become complicated as they tend to use separate equipment for turbine governing, generator excitation control, plant control and protection [Sah, July 2018].

A. *Automation and its Benefits in MHEPs*

'Automation of any system helps in sustainable operation and in this case the MHEPs' [Mehmet, November, 2022]. Kougias [October 2015] talks about the 'methodology for optimization of the complementarity between small-hydropower plants and solar PV systems. The methodology builds on an optimization algorithm that associates hydrological with solar irradiation information'. Performance and reliability related components of a MHEP and control system are based on the automation design and in many situations. Sah [July 2018] mentions about the 'automatic control of the level of the small hydro dam gates using backup of the water operated by a Stepper motor using a programmable logic controller (PLC)'. A PLC is a type of tiny computer that can receive data through its inputs and send operating instructions through its outputs. For automation, use of PLCs is one of the solutions.

Sobhan [December 2015] discusses in his paper Control and Monitoring of Automatic Generation in Micro Hydro Power Plant with Impulse Turbine and Synchronous Generator, about the computerized automatic control system with PID control technique for the synchronous mounted MHEP. Thamilmaran [August 2015] focuses on 'closed loop system of micro hydro power plant with change in output frequency as the control variable which can be fed into the PID controller and necessary actions can be taken so as to maintain constant parameters'. Jasa [April, 2012] in his paper 'PID Control for Micro-Hydro Power Plants Based on Neural Networ' focuses control circuit for a MHEP where the circuit is constructed on neural network based PID control by using the Brandt-L in algorithm to control the governor. The governor function is to regulate the amount volume of water running into turbine'.

Although PLC is a 'closed system', considerable amount of innovative programming needs to be undertaken, as there are various types of PLCs to perform a wide range of tasks for several situations [Mehtre, June 2022]. The greatest advantage of the PLCs is that they allow for custom-designed modifications, as well as time-to-time updates without the need for much re-wiring or hardware changes, a characteristic required in this era of fast changing technologies. As there are various types and different combinations of MHEP technologies, there is ample scope for research to be undertaken in this area of renewable hydro energy technologies.

B. *Sensors, Controllers, and Actuators in Automation*

'For monitoring and control of various MHEP parameters effectively, they need to be digitized for which various electronic devices such as digital sensors, relays have to be chosen and installed based on each particular situation [Mofidul, November 2022]. Maseda, [April 2021] 'describes a SCADA system that combines complexity and agility in the relationship between operator and machine to improve fault prognosis for undetermined root causes. It is recommended that industries continue to research and innovate to obtain the best possible performance outcomes from the potential of the smart factory. The development of more sophisticated SCADA systems to optimize sensor data management and the improvement of industrial predictive maintenance with the implementation of robust diagnosis tools are means to meet this challenge'.

Nongdhar [May 2017] describes about optimisation of a MHEP using an experimental Electronic Load Controllers (ELC) with MATLAB simulation 'in which no separate penstock is required to control the speed of the flow of water simulation. The ELC is an electronic device in which the output of the generator can be maintained constant instead of changing or fluctuating user loads, thereby eliminating the use of conventional governors resulting in making the system more reliable, efficient and economical. The ELC maintains a constant generator output by introducing a separate load called ballast load which absorbs the load required by the consumer'.

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'Optical fiber has proven to be a suitable a solution for systems implementing applications' [Marrazzo, November 2021] especially in the immediately vicinity as in this MHEP. Usually, 'all AC voltages are to be monitored/ controlled have to stepped down to 24 V DC to render them compatible with the PLC' [fullyautomation, W5].

V. Wireless Communication in MHEPs

Increasing the sustainability of the MHEP will attract more and more small-time entrepreneurs to invest and exploit the world's vast untapped rivers and streams for a greener world with renewable energy, ultimately generating more employment in the rural settings as well. 'In modern remote communication design, the use of IoT systems is spreading due to their ease of operation, provided features, and versatility. Low-cost IoT alternatives are currently implemented in domains such as medicine, industrial monitoring and control applications, and smart home automation' [Albita, February 2023]. In the paper 'Remote Control and Monitoring of a Small Hydro-Power Plant' [Krasteva, 2011] uses a distributed system consisting of three microcontrollers and is intended for the control and monitoring of the generic waterwheel of a small hydroelectric power station. However, the type of hydro turbine and the type of electric generator used in the study was not mentioned.

A. *Challenges of MHEPs with Wired Communication*

The challenges of a MHEP wired communication is that it requires an operator periodically inspecting it. This leads to the rising costs of operator payments due to the inspection trips costs for every malfunction, as fault events cannot be rapidly removed without that such visits. This also leads to increased downtime of the MHEP affecting its sustainability.

B. *Significance of Communication Systems in MHEPs*

'The use of modern digital data acquisition systems [Maurizio, 2015] considerably helps in monitoring and control of specific events for estimation of the degree of wear and the development of maintenance programs for specific devices and systems'. Mofidul [November 2022] mentions about the 'industrial internet of things (IIoT) that is used to digitize industrial sectors and applications which requires the integration of edge and cloud computing, cyber security, and artificial intelligence to enhance its efficiency, reliability, and sustainability'.

'Wireless control of equipment and functions can help MHEP owners to effectively monitor the operation of multiple facilities from one place. It enables them to take quick, well-informed decisions that have bearing on the overall productivity and profitability of the MHEP. There is further scope for greater sustainability of MHEPs, if electronics and telecommunication systems are integrated using modern technologies such as PLC, IoT, and such others' [Kumar, December 2022].

'LTE-M, also referred to as LTE CAT-M1 device is a simpler version of LTE, designed specifically to work with battery power. These fall under the category of low-power wide-area networks (LPWAN) as it can operate even in a 4G band' [euristiq, W6]. Using 4G for IoT is one of the leading options, as it offers IoT connectivity for many types of use. It allows these devices to send and receive data over cellular networks in a much more power-efficiently.

Often IoTs are developed and managed based on Android apps and hence their popularity. IoT developers prefer Android due to its low costs. Benouda [March, 2021] says 'Android is open source, virtually anyone can modify it and utilize its source code in virtually any tool or gadget. IoT devices generate a significant quantity of data that can be viewed and accessed from anywhere in the world. This data may be transformed to produce practical insights, predict solutions, anticipate events, establish patterns, and instruct everyday objects to optimize themselves'

VI. Integration of Automation and Wireless Communication and Predictability in MHEPs

The challenge is the availability and the quality of data which will go a long way in uniting wireless technologies (such as digital sensors, IoT and others) with prediction models to improve the performance of MHEPs.

A. *Synergy of Automation and Wireless Communication in MHEPs*

Bernardes [February, 2022] says that over the years, several studies have explored Machine Learning (ML) techniques to optimize large hydropower plants' dispatch, being applied in the pre-operation, real-time and post-operation phases using sophisticated and expensive systems. But these are yet to be designed and implemented I MHEPs.

B. *Remote Monitoring and Prediction for Enhanced MHEP Performance and Sustainability*

The challenge is the availability and the quality of data which will go a long way in uniting wireless technologies (such as digital sensors, IoT and others) with AI algorithms to improve the performance of MHEPs. Additionally, if the

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power generation from the MHEP can be predicted based on the climatic conditions it will be beneficial for the entrepreneur and energy companies to plan for sustainable operations with minimum disruptions in the energy supply. Thus, it helps in planning the cash inflows as well. In other words, in optimizing the energy supply and demand results in efficient energy distribution, reduced carbon footprint, better control of energy usage resulting in money savings.

Hammid [2018] concentrates on 'applying on Artificial Neural Networks (ANNs) by approaching of Feed-Forward, Back-Propagation to make performance predictions of a general hydropower plant at the Himreen lake dam-Diyala in terms of net turbine head, flow rate of water and power production that data gathered during research over a 10-year period'. If power consumers use the energy generated on site or close to the point of generation such as MHEPs, it is quite sustainable. Ali [2018] 'discusses a fuzzy – neuro model is developed to forecast a year ahead load in relation to weather parameter (temperature and humidity) in Mubi, Adamawa State. It is observed that: electrical load increased with increase in temperature and relative humidity does not show notable effect on electrical load'.

VII. CHALLENGES AND FUTURE PERSPECTIVES

Considerable research for automation of large hydro plants have been done [Bernades, February 2022] to render them sustainable. However, it is not the case of micro-hydro electric plants coupled with squirrel cage induction generators that are generally owned by small-time entrepreneurs. Kolar [2022] states that 'Modern maintenance strategies, such as predictive and prescriptive maintenance, which is derived from the concept of Industry and Maintenance 4.0, involve the application of the Industrial Internet of Things (IIoT) to connect maintenance objects enabling data collection and analysis that can help make better decisions on maintenance activities. Data collection is the initial step and the foundation of any modern Predictive or Prescriptive maintenance strategy because it collects data that can then be analysed to provide useful information about the state of maintenance objects. Condition monitoring of rotary equipment is one of the most popular maintenance methods because it can distinguish machine state between multiple fault types'.

VIII. CONCLUSION

The real challenges of MHEPs are manifold and two of them being automation and wireless connectivity from remote places for their sustainable operation. As the MHEPs are of various types, there is no 'one-solution-fits for all' types of MHEPs. Research has yet to take place to find solutions to optimisation of each particular type of MHEP coupled with different types of electric generators for their sustainable operations.

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