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Article

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Design for localisation: A case study in the development and implementation of a low head propeller turbine in Nepal

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ABSTRACT

This paper proposes a methodology for “design for localisation” that addresses the challenge of designing a product for local manufacture and use, whilst considering the production process availability and the context of the local geographic area. The methodology is derived from a case study of the development of a propeller turbine in Nepal. In the case study, the initial challenge was the absence of a low head turbine that could be manufactured, used and repaired in Nepal. A potential solution from previous academic work was identified however its intended operating environment differed considerably. Through identification of the specific local requirements, the design priorities for individual sub-systems in the new context were developed. Using three examples, design changes driven by improving the ease of manufacture and applicability to the local context are explained. Multiple phases of field and laboratory-based testing were used to validate, adapt and improve the design and its method for implementation. The experiences of the case study lead to three rules for design for localisation using an identified potential solution for a local problem: firstly, to derive local product requirements; secondly to develop solutions appropriate for local manufacturing; and finally, to conduct field-testing phases to ensure the product is suitable for its intended application.

1. Introduction

Improvements in transport, logistics and automation have led to global supply chains for manufactured goods. This allows high value machinery to be used to manufacture precision products whilst utilising lower-cost labour to reduce product costs (Koren, 2010). However, this globalised supply can result in products that do not account for the local market or consumers and cannot be maintained when they fail.

In opposition to this, fields including “appropriate technology” (Murphy et al., 2009), “human centred design” (Giacomin, 2014), “design global-manufacture local” (Kostakis et al., 2015) and “design for the developing world” (Mattson and Wood, 2014) have emerged to describe design approaches that are targeted at the needs of local users and markets. Within these fields, the risks associated with importing foreign technologies without adaption to the local context are often mentioned (Murphy et al., 2009; Mattson and Wood, 2014; Dunn, 1979).

In this paper, the concept of design for localisation is introduced, whereby an existing design is adapted for local manufacture, assembly and use in a new geographic location. There are two major criteria that are considered within this design process:

1. Designed to be manufactured and repaired in the local geographical region of use whilst considering the availability of skills, processes and materials.
2. Designed for the local geographical region based upon consideration of the technical, social, economic and environmental context.

Processes of design for localisation have often occurred in the field of renewable energy, particularly hydropower (Leary et al., 2012; Katuwal and Alok, 2009; Paish, 2002). For communities in off-grid rural areas, pico-hydropower (generation at less than 5 kW) can provide a reliable form of generation and locally made hydro-turbines are often a cost-effective and sustainable solution (Williamson et al., 2019; Alsop

Abbreviations: UC, University of Canterbury; NHE, Nepal Hydro and Electric; PEEDA, People, Energy and Environment Development Association; KAPEG, Kathmandu Power and Electronics Group; OPS, Oshin Power Services.

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et al., 2018). In Nepal, Pelton turbine designs have been locally adapted for use at the pico-hydro scale through the development of Peltric sets (Nepal Micro Hydro Development Association, 2014). For local communities, proximity to manufacturers reduces delivery costs and allows locally relevant technical support to be provided during installation and throughout the project lifecycle. Many communities do not have access to the head required for Peltric sets, however, there are often sites with a small head and enough flow to generate electricity. Whilst Crossflow turbines can operate with heads as low as 2.5 m (Ossberger), the Crossflow turbines manufactured in Nepal are typically used at sites with heads in excess of 5 m. Research has proven that pico-hydro turbines for heads below 5 m can achieve efficiencies in excess of 70% without complex manufacturing equipment (Williams and Simpson, 2009). However, it has not led to widespread replication in the manner of the Peltric set. At the pico-hydro scale, the market for very low head turbines (less than 5 m head) largely consists of standardised turbines and kits for the home energy market (Paish, 2002; Powerspout, 2019; Asian Phoenix Resources Ltd, 2019). These designs are often inappropriate for rural customers as advice and spare parts are difficult to access.

This paper uses the development of a low head propeller type turbine in Nepal as a case study to propose a three-step methodology for design for localisation. The presented methodology draws on the approaches of other design fields that are focused on people and their needs; however, it places a greater emphasis on understanding the manufacturing capability available in the local context. The paper describes the design and implementation approach for the technology as a results of collaborative inputs from academia, industry and a non-governmental organisation (NGO). Section 2 outlines the start of the localisation process, identifying the socio-techno-economic environment and introducing the turbine design. Section 3 describes the approach that enabled localisation of the design, utilising specific examples to demonstrate how challenges were overcome. Section 4 highlights the importance of laboratory testing and field-based monitoring in improving the design and its implementation. Section 5 identifies the key processes required for design for localisation from the presented case study and highlights further work for its refinement.

2. Design requirements for the local context

In Nepal, the micro-hydropower industry has been successful in improving access to energy in rural communities. It is estimated that 3300 pico-, micro- and mini hydropower plants have been installed in Nepal (Nepal Micro Hydro Development Association). Most of these sites are managed and operated by local communities. The successful operation of these plants depends not only on the performance of the technology but also on the community's interaction with it. Previous research into rural electrification has suggested that the interaction between technology, people and institutions results in the formation of a socio-technical system (Ahlborg and Sjöstedt, 2015). Furthermore, the dynamic relationships between sub-systems means the overall system and how well it performs may continue to change with time (Ulsrud et al., 2011). When proposing a solution, it is necessary to consider the design requirements within this context.

For the propeller turbine system, the specific design requirements were derived through an understanding of the installation environment. The technology was intended to serve rural sites in Nepal where the available head was insufficient for Peltric sets or Crossflow turbines. Table 1 outlines considerations relating to the local context and their effect on the system requirements. The national rate of electrification in Nepal has improved from 15% in 2000 to 77% in 2016 (International Energy Agency, 2017), however, there are rural communities where the context and requirements of renewable energy technology are similar to 1997 when the development of the propeller turbine set began. The table has been populated using information from available literature and the personal experiences of the authors.

Table 1

Considerations that affect the socio-technical system design specification for a Nepali context.

No.	Consideration	Design requirement
1	Many rural areas are located far from the industrial centres of Kathmandu and Butwal.	Reliability and simplicity of the design should be a key priority.
2	Sites could be located far from nearest road head.	Individual components should be portable on foot.
3	Agricultural canals for irrigation are common across Nepal.	Existing civil works can be used to divert water to the turbine.
4	Monsoon season in Nepal often leads to significant flooding.	Electrical components must be secure from flooding.
5	The rivers in Nepal carry a very high sediment content during the monsoon season.	The turbine must be resilient to a high sediment content in the flow.
6	Water flow may include vegetation and other debris.	Through filtration or alternative methods, the turbine should be resilient to vegetation and debris that are typical in the local area.
7	The technology is owned, managed and operated by a community.	<ul style="list-style-type: none"> The system must be simple to operate even by someone with little technical expertise. Electricity tariffs must be collected to pay for operation and maintenance of the technology.
8	Projects where consumers make no financial contribution are likely to fall into disrepair.	End users should make a financial contribution to the scheme prior to installation.
9	There are limited opportunities for income generation in rural areas of Nepal (Gurung et al., 2011).	If possible, the technology should improve opportunities for income generation.
10	Income of consumers is typically low.	<ul style="list-style-type: none"> The cost of the technology should be minimised. Tariffs must be set at an appropriate level so that consumers can pay regularly.
11	Communities in Nepal often consist of multiple caste groups with more disadvantaged groups less able to access assets and make an income (Bhandari, 2013).	The provision of electricity should not discriminate consumers who have less ability to pay.
12	There is typically a good availability of unskilled labour in rural Nepali communities.	End users should provide labour in kind as a contribution during the construction works.
13	There may be water rights issues associated with using water to generate power.	Sites should be selected carefully to avoid creating conflict.
14	Communities may be unfamiliar with the concept of hydropower.	Communities should be educated to understand the technology.
15	Some communities have no access to a reliable supply of electricity. In 2016, an estimated 7 million people had no access to electricity whilst 20 million relied on biomass for cooking (International Energy Agency, 2017).	Consumers need to understand using electricity, electric lighting and electrical appliances.
16	Every community is socially and economically unique whilst environmental and technical features of each site will also vary.	The most effective process for implementation will vary from one site to the next.
17	Paying for energy services on a monthly basis may be unfamiliar to rural communities.	The payment process and its importance should be explained to consumers.

A family of turbine designs developed at the University of Canterbury (UC) in New Zealand was found to fulfil many of the technical design requirements for a low head turbine in Nepal. From 1981, UC began research into developing a low head micro-hydro turbine that could provide a "one-family-farm" with a viable power source (Alexander and Giddens, 2008). UC's objective was to produce a set of cost-effective designs ready for installation at sites with appropriate geography in New Zealand. As these sites were likely to be in remote areas, reliability and repairability are key drivers. The designs were all vertical shaft propeller turbines, standardised to minimise their cost and

maximise simplicity. The sizes of turbine were considered in discrete steps to correspond to typical generator specifications. Alongside the turbine and generator, an electrical control system was developed. This electronic load controller (ELC) allowed turbines to run at a constant speed by maintaining a constant resistive mechanical load; using a dummy load that varied in response to changes in the consumer load. Consequently, no moving guide vanes or blade actuation were required which reduced the number of parts, cost and maintenance requirements. The high specific speed of a propeller turbine allowed it to be directly coupled with a generator. This avoided the need for a transmission system (such as a belt drive or gearbox) which also reduced the number of parts, cost and maintenance requirements. Reaction-type, propeller turbines are inherently good at dealing with silt which means complex and expensive de-silting civil structures were not required. Another advantage was that a draft tube could be used, allowing the generator and electrical components to be positioned safely above the flood plain. These designs features made the propeller turbine appropriate to be localised for use in Nepal. Furthermore, the range of designs developed at UC made it possible to match the system flow rate to that available in irrigation canals in Nepal. The propeller turbine hydropower plant consists of a number of sub-systems that collectively or individually satisfy the design requirements identified. [Table 2](#) lists these sub-systems and their functions.

To maximise the simplicity of the design for the operators, the integration of these components with one another was critical. This was also true for the mini-grid sub-system that comprised the transmission & distribution (T&D) network and the household loads. Within each household, the interface between consumers and the technology needed to be safe, reliable and easy to use. An understanding of the local context demonstrates the importance of these interfaces, both technically and socially. When implementing the technology, it was effective to consider all the equipment supplied and installed by the manufacturer as a complete “propeller turbine set” including the T&D network. Alongside the requirements that affected the technology, the design requirements also established a range of other requirements for the effective implementation of the technology. Education through meeting with the community and the supply of relevant information in an accessible form were necessary to ensure the technology could operate sustainably.

3. Design and manufacture in the local context

From 1997, Nepal Hydro and Electric (NHE) began the process of developing several propeller turbine (PT) sets, known as the PT series. Using information from papers published by UC, an initial laboratory prototype model was specified, built and tested. This led to the development of 0.2 kW, 0.3 kW and 1 kW versions that were installed in the field. NHE were responsible for the design and manufacture of all hydro-mechanical and electrical sub-systems. In 2009, the rights to the technology were transferred to the People, Energy and Environment Development Association (PEEDA), an NGO focused on improving rural access to energy in Nepal ([People Energy & Environment Development](#)

[Association](#)). From this time, PEEDA have been technically assisted by Oshin Power Services (OPS), a micro-hydropower manufacturer and installer, and Kathmandu Alternative Power and Energy Group (KAPEG), a research organisation focused on electrical engineering in renewable energy ([Kathmandu Alternative Power and Energy Group, 2019](#)). OPS have undertaken the manufacture and installation of 0.3 kW, 1 kW and 3 kW versions of the propeller turbine set. Whilst, KAPEG have been responsible for the ongoing development of the ELC controller.

Throughout the localisation of the design, a considerable amount of research and development has occurred in the country of use. During the initial development at NHE, Nepali engineers were encouraged to devise and conduct their own tests on the sub-systems of the turbine. By encouraging an experimental approach, the engineers learnt to devise experiments that tested the equipment even to the point of failure. For the individuals, this improved their understanding of the equipment and its weaknesses, allowing them to suggest and implement design changes. The technology benefited from robust testing of all its sub-systems, with targeted experiments conducted by Nepali engineers who understood the installation environment.

Two turbine designs originally developed at UC have undergone a process of design for localisation. The first, referred to as the Mark 1 (MK1), was an open flume design using a guide vane assembly to generate tangential velocities in the flow. [Fig. 1](#) (a) and (b) shows the Mark 1 and Mark 2 designs respectively. The MK1 design placed the turbine in an open channel and had a tripod stand to elevate the generator above the water level. The long shaft meant that a water lubricated bearing was used below the runner housing to support the shaft. Experience in the field in Nepal with the MK1 design identified some commonly occurring technical problems. For example, if the water lubricated bearing was allowed to run ‘dry’ or semi ‘dry’ (which could occur during start-up), excessive temperatures quickly built up. Technical data from UC was used in the development of a Mark 2 (MK2) design in Nepal. The main change in the design was the introduction of a scroll casing which meant that the generator could be mounted onto the enclosed casing, reducing the shaft length and removing the need for the water lubricated bearing.

The process of design for localisation demands that the technology can be locally manufactured with the skills, equipment and materials available, and specifically adapted to the requirements of local users. In this section, 3 specific examples of design for localisation are presented.

3.1. Casing

The transition from the MK1 to the MK2 design resulted in the addition of the scroll casing which simplified the design and improved both reliability and performance. To maximise the efficiency of the turbine, it was important to ensure that the tips of the runner blades ran concentrically to the runner housing, with the smallest clearance possible.

During the manufacture of the 0.3 kW MK2 at NHE and later at OPS, an engine lathe was used to machine the inner diameter of the runner housing and the top surface of the scroll casing after their fabrication. This ensured a reasonable parallelism tolerance could be achieved between the generator shaft and the runner housing. However, at the 1 kW scale, the lathe at OPS was not large enough to rotate the scroll casing. Initially, the machining operations on this part took over 70 h and were sub-contracted to a machinist with a larger engine lathe. To repeat the same method for a 3 kW design would have required an even larger lathe. Across Nepal, there are only a few manufacturers with engine lathes large enough to accommodate this production process. To enable the production of this component to take place at OPS (and therefore other manufacturers of a similar size), an alternative process was developed.

In this new process, precision machining of the runner housing took place prior to fabrication with the scroll casing. The top plate was aligned concentrically to the runner housing using a jig. [Fig. 2](#) shows the

Table 2
Sub-systems of the propeller turbine plant.

Sub-system	Function
Trash rack and/or screening	Extract required flow from the civil structure and prevent ingress of vegetation and debris.
Forebay tank with spillway	Maintains a fixed positive head.
Inlet	Transfer flow from forebay tank into the turbine.
Turbine	Convert potential and kinetic energy of water into shaft power.
Generator	Convert shaft power into electrical power.
Control system	Maintain the generator at a constant speed of operation regardless of consumer load.
Draft tube	Allows suction head to be utilised.

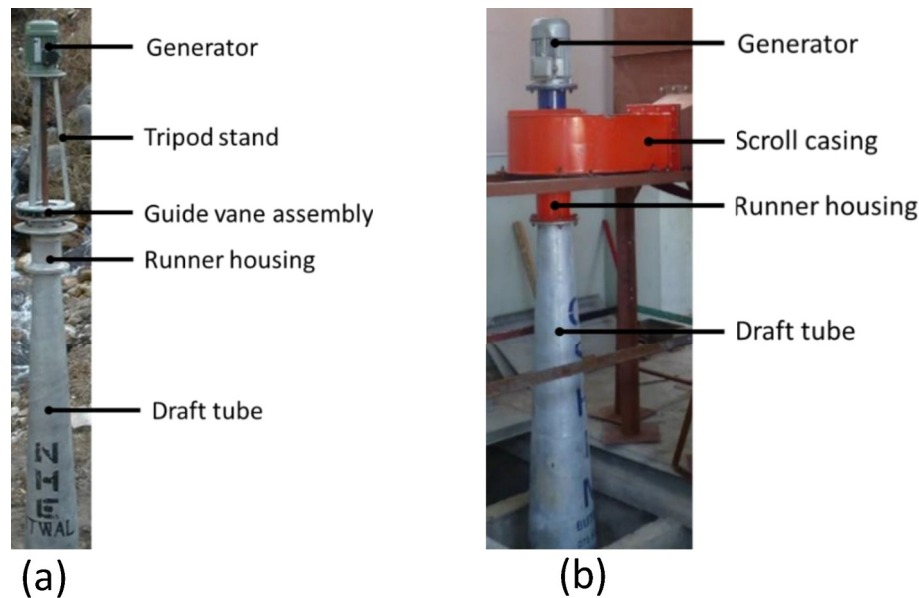


Fig. 1. (a) Mark 1 and (b) Mark 2 propeller turbines developed in Nepal.

second jig that was used to align the generator assembly with the scroll casing. This jig was attached to the shaft in place of the runner and located the shaft within the runner housing. With this jig in place, the generator assembly was tack welded and the fixing could be drilled and tapped.

This change to the design allowed all the manufacturing processes to take place at OPS and has been successfully used in the production of two 1 kW MK2 and one 3 kW MK2 turbines. The process of localisation has reduced the complexity of the manufacturing process and improved its availability to smaller manufacturing workshops. The new process requires the production of the connection jig, but this component can then be used repeatedly. With this jig, all of the manufacturing processes can take place within the small workshops that are typical in Nepal. Consequently, the additional cost associated with using a lathe at a larger manufacturer is avoided. With the new manufacturing process, it should be considered that the welding of the runner housing takes place after machining, consequently the cylindricity of this component is likely to be distorted. In addition, the alignment process results in a larger tolerance for the parallelism between the shaft and runner housing. A comparative performance test for the two methods would

provide insight into the trade-off between ease of manufacture and performance.

3.2. Electronic load controller

A design requirement of the propeller turbine set was that it should be capable of powering equipment that could be used for income generation. Achieving this could improve livelihoods and the income of the power plant. At the pico-hydro scale, it is common to use an induction motor as a generator (IMAG) due to their high availability, relatively low cost and robust design (Ekanayake, 2002). Many income generating activities or “productive end uses” such as grinding mills, sawmills and sewing machines require the use of motors. When powering a motor, a large inrush current occurs when a voltage is applied whilst the motor’s shaft is stationary (Jordan, 1994). The inrush current can be several times greater than the rated load current and the resulting droop in voltage prevents the motor from starting.

With the aim of improving quality control and exploring batch production, KAPEG were commissioned by PEEDA to develop an excitation system and electronic load controller (ELC) for a 0.3 kW propeller turbine set (Gautam et al., 2013). KAPEG developed a testing rig, shown in Fig. 3, to investigate using an IMAG to power an electric motor. Using a transmission belt, a DC motor could be used to drive a 3-phase IMAG (Gautam et al., 2013). A variable capacitor bank connected across the generator poles could be used to vary the capacitance across the generator phases. The IMAG was also connected in parallel to a main load, dump load and ELC. The IMAG’s ability to start an inductive load was tested using a hand drill driven by an electric motor rated at 0.3 kW.

Using the testing rig, the objective was to identify a selection of capacitors that would allow the IMAG to drive an inductive load. Alongside the selection of capacitors, a new ELC was integrated which limited the droop in voltage to 190 V and ensured recovery to the design point voltage of 230 V in 0.5 s. In British Standards Institution (2010), voltage sags are defined as being less than 85% of the nominal voltage and are considered acceptable if occurring for less than 1 min. With the new ELC, the droop corresponded to 83% of the nominal voltage, lasted for less than 0.5s and therefore can be considered acceptable. This arrangement was tested on site with the IMAG driven by a 0.3 kW MK2 propeller turbine set.

Following the development of an effective prototype, KAPEG procured the equipment to manufacture their own printed circuit boards

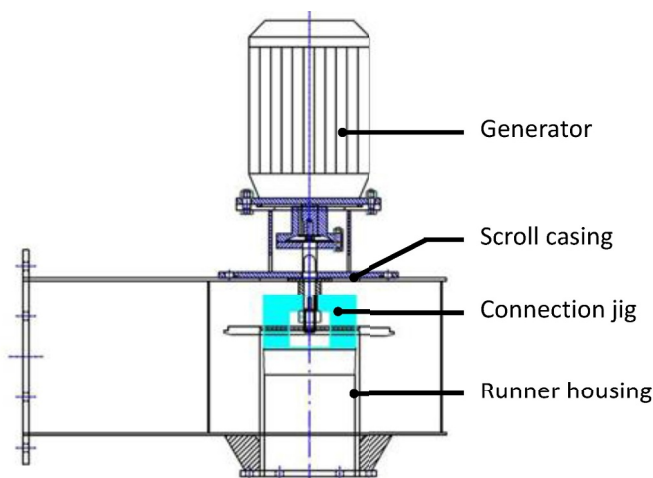


Fig. 2. Jig used to align generator assembly with volute casing in the MK2 version of the turbine.



Fig. 3. KAPEG's testing rig for the Electronic Load Controller, adapted from Gautam et al. (2013).

(PCBs). KAPEG tested their own PCBs along with those purchased from suppliers and found the quality comparable. As a result, KAPEG reduced the cost and lead time whilst increasing their own understanding, quality control and ability to integrate components. The resulting configuration of capacitors and controller have been adapted, tested (in the laboratory and field) and manufactured by KAPEG for both the 1 kW and 3 kW systems. The updated ELCs have typically operated for 1 year before requiring replacement. Lightning is often identified as the reason for failure but further work is required to understand and validate this claim.

3.3. Trash rack

For the reliability of hydro-turbines, it is important to prevent debris from passing through the turbine. In many parts of the world, small-scale hydropower schemes often use Coanda screens to effectively filter small particles whilst self-cleaning. These screens are rarely used in Nepal because of their high cost, Nepali manufacturers usually fabricate their own trash racks. For Crossflow and Pelton turbines, a fine trash rack is usually used in the forebay tank to filter water as it enters the penstock. The racks are fabricated from vertical strips of sheet steel, as shown in Fig. 4. The typical spacing of between 10 mm and 20 mm can still lead to the ingress of stones capable of damaging the runner (Alternative Energy Promotion Centre, 2013).

UC had experimented with a low-cost alternative to a Coanda screen

which had been installed at a test site. The design was intended to be maintenance-free using the energy from the water's head to filter debris from the water (Giddens, 1986). NHE's aim was to develop a screen where all the parts could be sourced, fabricated and repaired in Nepal. The screen needed to be robust, maintenance free and adapted to the local context; capable of filtering vegetation and other debris typically found in Nepal. NHE used a laboratory rig to test using perforated steel sheet as a self-cleaning screen. The performance of locally available perforated 0.8 and 2 mm thick sheet, both with 3 mm diameter holes, was compared. The sheets were tested in a straight and right-angle configuration. When placed at 90° to the channel, a flow deflector and baffle were developed which resulted in little change in the length of screen required. The two configurations made the screen applicable to a wider range of sites. The performance of the 2 mm sheet was favourable compared with the thinner sheet due to its greater rigidity and higher flow rate. On average, the extraction rate (e.g. the proportion of extracted flow to input flow) was 99% for the 2 mm sheet and 47% for the 0.8 mm sheet. The thinner sheet warped during handling and was not considered to be sufficiently durable. The rack was installed into sites with upright threaded bar allowing adjustment of the angle depending on the quantity and type of debris to be filtered. This allowed the rack to be optimised on site for specific operating conditions. The final form of the trash rack, shown in Fig. 5, was a simple welded fabrication with all the components available in the local Nepali market.



Fig. 4. Typical micro-hydropower trash rack in Nepal.

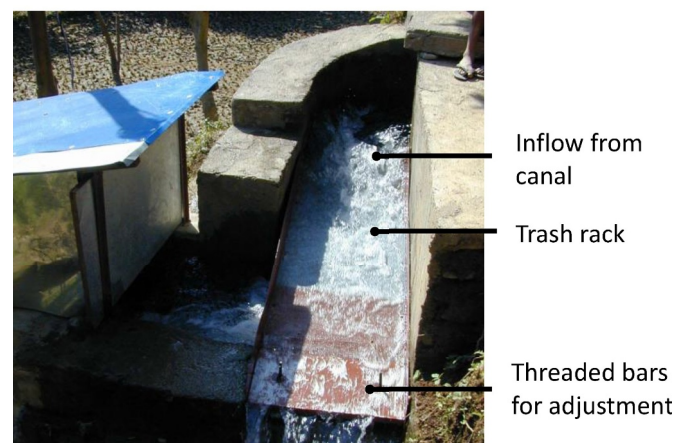


Fig. 5. PT trash rack localised for Nepali context.

4. Monitoring and testing

Throughout the development of the PT series, monitoring on site and testing in the laboratory have been used to improve technical designs and implementation approaches in the field. During the initial development, a laboratory developed at NHE was crucial in testing individual components and their integration in sub-systems. The testing rig consisted of an open flume which was fed by a pump. For the MK1, this allowed testing to closely replicate the conditions found on site. In the laboratory, a combination of a precision fabricated, Perspex housing and locally developed instrumentation could be used for flow visualisation and to analyse the turbine performance (Cox, 2001). The flow rate was measured using a calibrated, thin-plate rectangular notch weir. A calibrated pitot tube connected to a differential manometer was used to measure the water velocity (magnitude and direction) downstream of the runner which permitted an understanding about hydraulic losses in the turbine section. The shaft torque was measured using an inline torque sensor. Using this equipment along with a dump load to control the load on the generator, changes to hydraulic performance could be easily monitored. Engineers at NHE were encouraged to develop their own tests to improve the reliability, performance and safety of all components. The method and results for all these tests was recorded so that the product development path could be easily understood. Over a 10-year period more than 50 tests were carried out, these included testing of new and existing designs, and analysis of parts returned from the field.

4.1. Pilot programme in multiple locations

Butwal Technical Institute (BTI), a technical college, was responsible for conducting a monitoring programme of 3 PT MK1 turbines (Niraula, 2005). NHE were a partner in the programme and provided all the equipment, training and technical support to the engineers responsible for monitoring. As well as supporting the three field sites, NHE made a series of design changes based on reports from the field. The following section summarises the findings of a report published by BTI (Niraula, 2005). At the outset, the identification of sites for the project considered technical, social and economic factors. An upper limit of 50 households in a village ensured that all households could be connected and receive 20 W to power 2 compact fluorescent light (CFL) bulbs. This would also avoid creating conflict in larger communities where some households may not be connected. Choosing a location far from the national grid ensured that there was a demand for the technology. Similarly, by selecting communities with a lower income, it was expected that the communities would provide labour during construction. The demand for electricity and physical involvement of the community helped to develop a sense of ownership in the project. This sense of ownership and the overall sustainability of the project were strengthened through financial contributions from the beneficiaries. The selection of pilot sites allowed the technology to be tested in range of locations; the environmental and social differences were important in evaluating the suitability of the propeller turbine set for a range of sites. At each installation, practical training was delivered regarding operation, maintenance and repair to the selected operator. An operation and maintenance (O&M) guidebook, written in Nepali, and with clear images was also provided to operators. In addition, training for consumers explained electricity use and the importance of tariff payment. Training was intended to address the socio-technical considerations (such as No. 14 and No. 15 in Table 1) that cannot be tackled through physical design.

Over the course of the field monitoring, a number of problems were identified relating to the different sub-systems. The identification of these problems and the feedback to NHE meant they could be individually resolved at the time and targeted for remediation in future designs. To minimise the possibility of these problems occurring in new installations, there were typically three approaches that were taken: a

change in design, a change in procedure (during installation, operation and maintenance) or a change in behaviour.

The problems which led to a change in design tended to affect the propeller turbine set. Mechanical problems were often associated with shaft misalignment and its resulting vibration. To minimise the occurrence of misalignment, the design was updated to include securely fastened shims that would remain in place during transportation from the factory to the site. Shaft vibration also led to the stripping of a thread on a stub pin and the failure in a weld between the shaft and the runner. Later designs used a tapered pin which was resilient to vibration than the threaded pin. A shaft with a failed weld was replaced and all subsequent shaft welds were checked by NHE using non-destructive testing. Whilst in service, the tripod mounting bolts rusted. Later installations used higher quality bright zinc plated bolts. For the controller, improvements were made to the ELC after the ballast load was tampered with by members of the local community and the supplied CFLs were found to be burning out quickly.

A change in procedure for installation and operation was required in response to issues with the mini-grid. The distribution cable was fragile and often found to tear during installation, subsequently greater care was taken with both handling and routing of cables. At some sites, to increase available load, the community tampered with MCBs. Operators were advised that regular checking of these MCBs should form an important part of their O&M responsibilities. The actions of the community had a significant impact on the technical performance of the plant. The community had to change their behaviour to avoid damaging the plant or reducing the quality of service for themselves or others. When CFL bulbs broke, the usual response by the community was to replace them with cheaper incandescent bulbs. The higher power rating of these bulbs led to overloading of the system. Similarly, at another site, wealthier members of the community began using televisions. At one site, these problems were resolved when NHE staff instructed households to reduce their individual loads and continue to use CFL bulbs. At another site, the community independently introduced their own informal system which allowed only one television to be used each evening.

The pilot programme and results from experimental testing demonstrated a number of weaknesses in the MK1 design. The open flume design required the tripod, a long shaft and water lubricated bearing. This arrangement was found to be problematic and motivated the transition to the MK2, which addressed these problems through the introduction of the scroll casing. Three of the first MK2 turbines (rated at 0.2 and 0.3 kW) were known to have operated without serious issue for at least 6 years between 2005 and 2012. Later MK2 turbines have operated successfully for at least a year but several have been affected by environmental issues (a project was damaged by an earthquake and another due to a landslide) and another grid encroachment. In future, it would be advantageous to develop a simple checklist that could be completed periodically to gain an understanding of each turbine's durability.

Through monitoring, lessons were learnt regarding the design, implementation and the ways in which the technology was used. These lessons were used to make change to the design, the documentation supplied to operators and the community education approach. Acting on the failures and making appropriate changes was an important step in improving the reliability and sustainability of future projects.

4.2. Verification of the turbine performance at Kathmandu University

Following the progression to the MK2 design and the transfer of the technology to PEEDA in 2009, a 0.3 kW and 1 kW PT set were manufactured at OPS. The 300 W unit was installed in a field site and used to test KAPEG's controller and validate its integration with the other sub-systems. Subsequently, after the production of the first 1 kW MK2 propeller turbine set, laboratory testing was used to test the efficiency of the complete set and configure the ELC for the 1 kW unit. Testing was conducted at the turbine testing laboratory at Kathmandu University

(KU). The rig used a pump to feed a forebay tank, where the head in this mock forebay tank could be adjusted by changing the height of an overflow gate. The flow from the forebay tank passed through the turbine and into the draft tube which was positioned in a weir. Fig. 6 shows the testing rig at Kathmandu University.

During testing, the rating of capacitors in the C-2C arrangement across the induction motor were varied. The best performance was found when using a capacitance value of $17 \mu\text{F}$. This arrangement gave the best efficiency and most stable electrical output. Fig. 7 shows a graph of efficiency and flow rate against rotational speed using $17\text{--}34 \mu\text{F}$ arrangement of capacitors and a head of approximately 3.8 m.

The best efficiency of 54.3% occurred at a rotational speed of 1557 rpm with a head and flow rate of 3.8 m and 50.3 l/s respectively. The testing did not investigate the efficiency of the generator therefore the exact efficiency of separate components was not known. In Smith (1994), a motor of equal size to the one tested has an efficiency of 76% when operating as a generator at full load, hence the hydraulic efficiency of the turbine can be assumed to be approximately 71%. For comparison with the MK1, there is experimental test data from CU published in Parker (1996) for a turbine with a hydraulically similar design. During that testing, the best efficiency achieved was 56%. These results provide an indication of the efficiency achievable by the MK1 design, however, there are several factors that must be considered. Firstly, the CU prototype was a scaled down version with a maximum power generation of approximately in 600 W. Secondly, whilst largely similar, the MK1 turbines produced in Nepal had several deliberate design changes which may have affected the efficiency. Thirdly, there was likely to have been a difference in the quality of manufacturing between Nepal and New Zealand. Consequently, the results from the CU should only be used as an indication of the efficiency of the Nepali made MK1 turbine. However, the improvement from approximately 56% to the 71% achieved during testing at KU indicates a significant improvement in efficiency and validates the transition from the MK1 to the MK2 design.

The performance of the ELC was tested to ensure that the output voltage and frequency could be maintained at acceptable levels whilst the main load was changed. Two distribution boards were used to represent the ballast and main loads. The ELC ensures that there is sufficient ballast load to maintain a constant rotational speed of the runner. The test began with no main load whilst the ELC ensured that there was sufficient ballast load. As the main load increased, less load was diverted to the ballast load. Fig. 8 plots the main load voltage and frequency against the main load percentage. It can be seen that as the main load power increases, the voltage and frequency are maintained close to their design points of 230 V and 50 Hz respectively. The

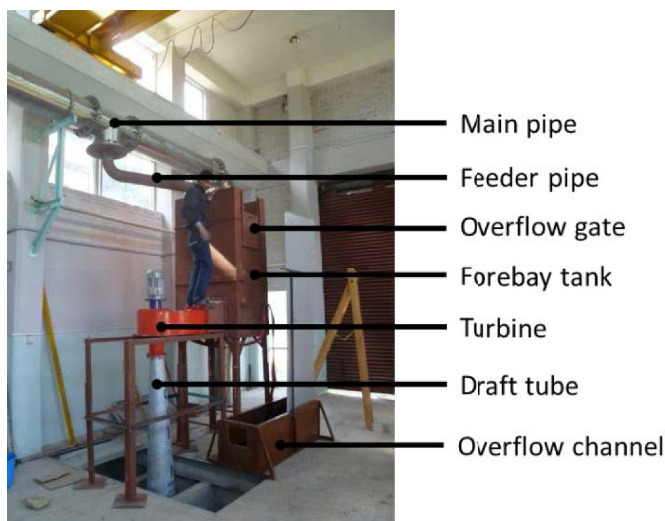


Fig. 6. Testing rig in the Turbine Testing Laboratory at Kathmandu University.

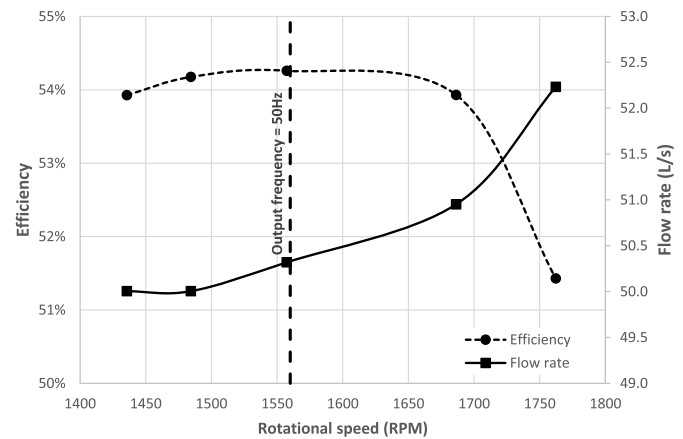


Fig. 7. Efficiency and flow rate against rotational speed for the MK2 turbine in laboratory testing at Kathmandu University.

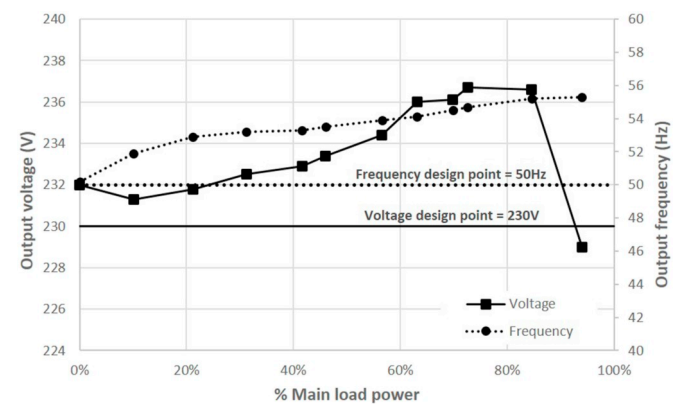


Fig. 8. Voltage and frequency changes during load variations in laboratory testing at Kathmandu University.

fluctuation in the values of voltage remain inside the suggested $\pm 10\%$ suggested by Nepal's national guidelines on power output from small-scale hydropower projects (Alternative Energy Promotion Centre, 2008). However, the suggested frequency limits of $\pm 5\%$ are exceeded whilst the main load power is between 60% and 85%.

From the testing of the 1 kW MK2 turbine, there were two significant outcomes. Firstly, the identification of the correct capacitors and the configuration of the ELC ensured that the control components of the MK2 were ready for field service. Secondly, the efficiency testing indicated a maximum water to wire efficiency of 54.3%. These two findings were important in demonstrating that the design for the MK2 had been effectively localised and was ready to be installed in the field.

5. Discussion

The development process of the low head propeller turbine led to a solution which satisfies the two aims identified in the introduction. In this case study, there were three key stages that enabled these aims to be satisfied. Firstly, understanding the local environment in establishing the design requirements was key to developing a robust system. The operating environment in Nepal is different to New Zealand (where the design originated), with the market, operating conditions, and a lack of skilled labour identified as some of the key differences. The specific requirements for Nepal influenced the solution choice, design changes and methods for its implementation. Secondly, technical capabilities in Nepal affected how the product sub-system could be manufactured. Design changes were required in response to material and process availability for the casing and trash rack. Finally, the laboratory and

field testing of the product was able to provide strong and robust feedback that resulted in a more reliable and suitable system. The product was tested and delivered as a complete system with tested interfaces between sub-systems.

Reflecting on the experiences of the case study and principles proposed in Mattson and Wood (2014), the following three steps are proposed to support the design for localisation methodology:

1. Understand local context for solution, deriving product requirements/specification

A requirement capture process needs to be undertaken, based upon the requirements of the solution and the technical, social, economic, political and natural environment that it will be implemented in. This derivation of local requirements can be used to inform a revised product specification for the adaption of the existing solution.

2. Develop design solutions for local manufacturing

The capabilities of the local manufacturing industry must be understood. A full assessment of the material, processes and skills available, including maximum size of work for the machinery, achievable tolerances and number of facilities and operators. Using this information, the design can be reviewed, any design changes identified, and a manufacturing plan can be developed.

3. Conduct local research and field-testing phases to ensure the product is suitable for the application

Once the product has been designed and manufactured, a comprehensive laboratory- and field- testing programme should take place. This will ensure the localisation modifications to the design work together as a whole, and the product system is able to operate as required to solve the initial problem whilst meeting the local requirements. This is a critical component of the process; without this, any bugs from the localisation process may cause the product to underperform, become unreliable or be unsuitable for local integration.

Alongside these three stages, the case study suggested three further principles are relevant throughout the process. Firstly, the design for localisation process may be non-linear. Lessons learnt during field testing phases improved understanding of the local context and led to further design changes. Secondly, the process of localisation should take place in the country of use. Nepali communities, engineers and implementors working in the field provided relevant input to the design based on an understanding of the rural context, the availability of materials and processes for manufacture. The short feedback loop between these stakeholders allowed changes to be implemented quickly. Thirdly, fulfilling the local requirements may require a range of supporting activities alongside the technology. Education and training were important in ensuring that communities were equipped to operate systems sustainably.

In comparison to the design approaches mentioned in the introduction, the objective of the proposed methodology is to develop forms of appropriate technology utilising existing designs. Like “human centred design”, the process considers social requirements from the outset. In addition, the successful technology implementation depends upon accompanying forms of education or knowledge sharing. In contrast to “design global – manufacture local”, greater emphasis is placed on understanding the design requirements in relation to the local context; in terms of both the manufacturing and implementation environments. However, the process has also depended on a relationship between academia and industry that is enabled by the internet. Throughout the case study, many of the principles within “design for the developing world” have been used. The proposed process should not be considered as being exclusive to a developing world context; it can be applied in any situation where a design requires adaption to new environment.

6. Conclusions

The ability for a product to be manufactured locally creates a product better suited to the local market and modified for local needs. It supports local businesses in developing their own design and manufacturing capability and encourages repair rather than replacement as product knowledge is held locally. Through a case study of a low head propeller turbine system in Nepal, this paper has proposed a three-step process for design for localisation:

1. Understand local context for solution, deriving product requirements/specification.
2. Develop design solutions for local manufacturing.
3. Conduct local research and field-testing phases to ensure the product is suitable for the application.

Alongside these three stages, experiences of the case study demonstrated several principles that supported the process. These were that the process may be non-linear, should take place in the country of use and that implementation of the technology requires a range of supporting activities. Using these principles, a commons-based system design could be developed for the local market, using local knowledge and capabilities to ensure the product is suitable. The case study of the low head propeller turbine showed that within the process there can be failures, but these enable additional knowledge and learning to be gained about the product, local environment and operation of the system. Therefore, failure within the product cycle should not be seen as a negative outcome, but an opportunity to ensure the product is more robust for the local market. Whilst PEEDA currently own the rights to this propeller turbine, the organisation is open to its transition into a fully open-source technology. For this to take place, further replication is needed. Furthermore, this replication must be closely documented so that information regarding these experiences is available. Within design for localisation, further work will involve identifying additional case studies that have followed a design for localisation process. It is expected that the additional information can support the methodology and lead to further guiding principles.

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