Photovoltaic versus Micro-Hydropower for Rural Non-Grid Connected Areas of Equatorial Sarawak

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***Abstract*—There is currently a large expansion in photovoltaic installation worldwide especially in the temperate regions of the world which have tended to influence electrical power decisions in developing countries at the equator. This research clearly justifies hydropower over photovoltaic electricity generation in non-grid connected regions of equatorial Sarawak, Malaysia. A case study was made of photovoltaic installations versus micro-hydropower installation in these regions. There are problems of micro-hydroelectricity especially during dry seasons but this work justifies allocating more resources in improving micro-hydroelectricity research such that eventually it will produce enough electricity even with the low water flow rate of the dry seasons. This research can be done locally compared to photovoltaics whose research tends to be mostly imported into Malaysia. Some comparisons are made to grid connected hydroelectric dams to depict capabilities of this technology given sufficient research allocations.**

***Index Terms*—Solar; PV; Micro-Hydro; Rural Electrification; Equatorial Regions.**

I. INTRODUCTION

Currently a high amount of finance is diverted for photovoltaic (PV) installations in non-grid connected regions of equatorial Sarawak, while this is not an optimum source of electric power for an equatorial region. The aim of this study is show this and to help divert some of this finance to micro-hydroelectricity (MHEP).

For this research, a case study was made of a solar power installation in Kuching and one in Bario, Sarawak. A case study was also made on the MHEP project in Bario, Sarawak.

In the electrification of rural non-grid connected regions of equatorial Sarawak, Malaysia, there are only two competing sources of green electric power generation, PV and MHEP. Wind turbines have been tried without success even in windy mountainous areas. Historically, the English sailors used to worry about the equator and called it “doldrums” because there is very little wind there to move their sailing ships [1]. In recent years, many PV projects are being implemented in Sarawak and the rest of Malaysia despite the many major disadvantages in implementing such technologies here. The drive to install PV is prompted by emulation of activities of the temperate countries where most of the educated elite of the world are located. Two example evidences of such copying of designs from temperate countries, without considering the local climatic conditions are as follows. The Main Switch Board (MSB) of the engineering building of Universiti Malaysia Sarawak (UNIMAS) is located in the underground level; flooding of this room is common because Sarawak has a 390% [2,11] more rain than temperate countries where designs are generally done. Another example is a train station in equatorial Malaysia (Kuala Lumpur Railway Station) which is built to withstand almost two meter of snow [3].

II. DATA AND OBSERVATIONS

The heavy rains result in the five factors listed in the next five paragraphs below which indicate that tapping solar power is not conducive to equatorial Sarawak.

Figure 1: Above is view of clouds over Sarawak from ground level on a typical morning. On right is a picture of clouds taken from a plane which depicts the vertical height of clouds

The temperature during day time when the PV is functioning in Sarawak averages around 30ºC but it can reach up to 36ºC [4]. Such a high temperature reduces PV voltage and thereby its energy production efficiency. PV is excited by certain frequencies of light and not the infrared portion (heat) of EM spectrum.

Fungus grows rapidly in equatorial countries. This fungus actually consumes minerals on the glass panel, eventually leaving them slightly opaque to the required frequency of light from the sun [5].

Most common batteries operate at temperatures below 25ºC [6] and will reach the end of their life span much faster above this temperature.

Sudden cloud cover is the next problem. Even if batteries are not used and solar panels are grid-connected (or as in a non-grid connected village depending on multiple power sources), a sudden cloud cover can remove a dangerous amount of power from the grid. Such a sudden cloud cover was experienced in Hawaii in the early part of 2015 which damaged grid equipment because 70 to 80 percent of power output from the PV was taken out in less than a minute. As shown in Table 2, the only generator that can supply power within a minute is HEP, and Hawaii only has a minuscule (0.3%) amount of HEP [7].

The above factors indicate that for Sarawak to pursue PV is like engaging in an activity with a handicap. In each region of the world, a study of the region's positives for a particular energy generation must be done before embarking on an energy project. In Perth, Australia for example, there is almost perfect conditions for PV; the sky is mostly cloudless and the low ambient temperature is optimum for PV [8]. But Perth, Australian researcher cannot easily do MHEP research. The researchers there are forced to use the city's drain for MHEP research [9].

Contractors, people in villages with solar projects, technicians, engineers and power company staff have reported that almost all PV projects in Sarawak have failed after about two years [10]. PV projects fail mainly because lead-acid batteries (car battery technology) is used, which has an empirical life span of about two years though they can be advertised to last about five years; improper maintenance could be the problem. If NiCd batteries are used, as is used for all substations of the Local Electrical Authority (LEA), the life span of the PV project would be reasonable. NiCd batteries can last up to 20 years but are expensive [10]. So unless contractors are forced to use NiCd batteries, they will not use it because they cost up to three times the price. And in the two years it takes for the lead-acid batteries to fail, the contractors would have collected all their profits for the project.

The PV industry is promoting itself via a little lie. Literature states that PV plants are 100MW, 300MW etc.; while it is actually 0MW all night and very little power on days with heavy cloud cover. Comparatively, the Batang Ai HEP power plant in Sarawak has a stated figure is 104MW and it can produce 104MW throughout the year. The Batang Ai dam is also high up in reliability compared to all other power stations [12].

Figure 3 shows solar panels installed on top of a building of the LEA. Data was collected of the solar power output for a span of one year. The results are shown in Figure 2.

February was an exceptionally cloudy and wet month with record flooding occurring in Kuching, Sarawak. Consecutive days of heavy and dark clouds were common during this month. So during the month of February 2016, this PV panel would not be of service to a household using it to produce electricity. This 7.68m X 3.84m PV panel can power eight 38 watt fluorescent lamps. The panel is connected in parallel to a bank of lead-acid batteries. After three consecutive cloudy days, the “low battery” LED (Light Emitting Diode) lights up. And three consecutive cloudy days are common in the rainy season of Sarawak.

The size of the solar panels (and therefore cost) to produce such low power seems inadequate compared to a MHEP station shown in Figure 4 that comfortably supplies power day and night for a village in Bario, Sarawak. This MHEP can supply 55 CFL (Compact Florescent Lights), five washing machines and 10 televisions. The dam measures 15m X 5m X 1.5m. Water flows out from the bottom of the dam via a one 0.3m (one foot) diameter HDPE (High-Density Polyethylene) pipe. About 21 m down from the dam is a forebay whose function is to further stabilize the erratic pressure of river and also collect river sand at the bottom. This sand is flushed out once in a while by opening a ball valve on a smaller diameter PVC pipe connected to the bottom of the forebay. This forebay measures 6m X 3m X 4m. Slightly above this PVC pipe is again the 0.3m (one foot) diameter HDPE pipe outlet. This HDPE pipe then goes down about a kilometer to the Power House which has the turbine and generator, whose measurements are 3m X 2m.

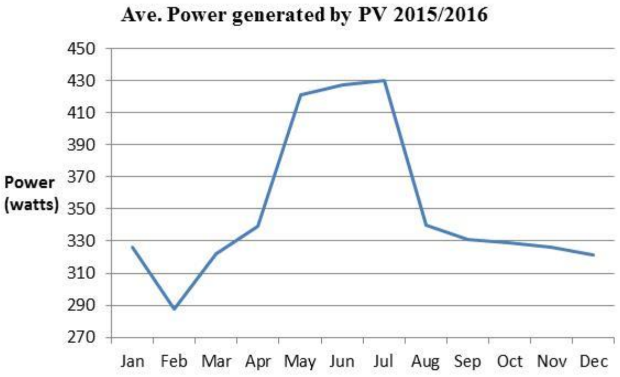

Figure 2: Solar power output data over one year (2015/2016) from the solar panel

Figure 3: Solar panels installed on the roof of the LEA

Figure 4: A micro-HEP turbine (blue, yellow) and generator (orange) located in Bario, Sarawak.

An attempt was made to collect data from all the failed solar projects of the LEA but they apparently do not keep records of all the solar projects in the deep rural villages. It only has records of solar projects which are less than two years old which were recently handed over to them. Also most of the solar projects were sponsored by the Federal Government, International bodies or religious organizations. Often it is in the best interest of the contractors for these organizations not to report to the LEA, in case they cause impediments to their activities of installing the PV system. Once a contractor is given the project, their drive is to finish it or else they cannot collect their profits [13]. A solar project was recently handed over to the LEA in Bario, Sarawak and detailed calculations were done to compare it to the MHEP project done by UNIMAS in the same village. The results are as shown in Table 1.

Table 1
Cost price and land area used for 18kW Micro Hydro versus an equivalent sized PV system

System	Cost price (US$)	Land area (m^2)
PV	4574320	384
MHEP	100000	15

As can be seen from Table 1, an 18kW PV system cost 46 times more than an 18 kW MHEP system. This initially seems illogical because it is common knowledge that the cost of PV has fallen 80% since 2008 mainly due to production in China [14]. But the biggest cost for the PV system is the deep cycle lead-acid batteries. Besides, all the components of the MHEP can be made locally, except the generator which is normally imported from China (Cummins brand).

For the PV system, all components are imported into Sarawak. The design of this PV system envisages two batteries for one home. There are currently 170 homes and 700 batteries with 1000 PV panels. The design projected that the number of homes will increase to 350. The two batteries per home can cater for nightfall but not consecutive days of dark clouds. It is for this reason that this PV system is backed up by three diesel generators, with a combined capacity of 1.15MW; the PV system is designed for 906kWp (watt peak). The cost of this system is extrapolated to derive an equivalent cost for an 18kW system shown in Table 1. Table 1 also shows that the land area used by the PV system is 2.5 times larger than the HEP system. This is equivalent to the space of 3.5 basketball court area, while the MHEP utilizes less than one basketball court area.

The main reason most solar projects fail is because no-one is coming up with the money to replace the lead-acid batteries after two years. If this once in two years change in the battery is included in Table 1, the price of a working PV system by the third year will require another US$510,771, causing the total cost to skyrocket to US$1,714,537 by the third year. While the well-designed MHEP system will only need regular greasing of the turbine and possibly a change of the turbine blades as they get damaged when water mixed with river sand blows on them. A replacement turbine blade will only cost only about US$150.

The lead-acid batteries used tend to be sized, 0.8m X 0.6m X 0.3m. These are expensive deep cycle lead-acid batteries costs about US$2,806 each. Though they are called deep-cycle, only half their rated energy capacity can be utilized. Meaning 500Ah can be drawn from a 1000Ah rated battery and if more is drawn; its life span will be drastically reduced. But a 50% discharge capacity of these batteries compares to only 20% for normal car lead acid batteries. But for a car, the battery sends out about 70 amperes upon starting, thenceforth the alternator generates most of the power for the car. In a PV installation, energy could be taken out of the battery all night, so 20% discharge capacity is not sufficient. These deep cycle batteries can be cycled from 500-1000 times at below 25ºC ambient temperature [15]. Many suppliers specify that their deep cycle lead-acid batteries can last five years but empirical observation in Sarawak is around two years, probably due to the higher ambient temperature and distilled water not diligently topped up.

The LEA did not have that much success with mini-HEP either, but three mini-HEPs (Gading, Sedako, Peninden) are running efficiently while Sungai Pasir is being repaired due to a leaking problem. It has to be noted for future engineering developments that the ones that are working well are Japanese built. Engineers in a large corporation like the LEA will tend not to stay in mini-HEP projects because these are not the income centers so remaining there could impact their annual reviews. These scenarios have made the LEA management view micro and mini HEP negatively. It is for these reasons that a university like UNIMAS should do the research for corporations like the LEA. University researchers are rated for their research and publications rather than their income generation. Research at UNIMAS can identify the remaining weakness in MHEP projects implemented all over the state. The avenues for improvement of MHEP projects are explained in the next six paragraphs.

Better civil engineering in the construction of the dam and forebay. The current construction does not meet stringent specifications because of the difficulty of access to these rural areas.

The air removal from the HDPE pipe can be improved with the mechanical engineering innovations such as air scoop [16].

The microcontroller-triac system for the RPM control of the HEP system can be fully be developed locally. The basic logic of this is when the water pressure is too high; electricity is dumped into big resistors called ballast. This will cause the current flowing in the stator coils of the generator to increase, making them more magnetic, thereby making it harder for the rotor to turn and consequently reducing the frequency of the outgoing AC voltage wave.

The system to maximize the pressure of the spraying water onto the turbine blades can be improved with the latest development in mechanical engineering. Orifice shapes design can increase the pressure of the spraying water without increasing the water flow rate. These can be adapted from the latest pressure washer's designs. The portion that holds the turbine and generator should be precasted in towns and freighted to the rural areas. This is because the turbine and generator are continuously vibrating so the concrete that holds them must be well made. In rural areas, this is empirically an Achilles' heel in MHEP projects due to the deficiency in civil engineering knowledge and construction materials.

The sluice gate is a metal door openable with a car steering like wheel, to release the dammed water. This can be designed and built locally with continuously improved design incorporating features of local environments.

Research in all the above areas will make MHEP generation viable for rural non-grid connected villages in Sarawak. The development of this technology can also help the LEA improve the construction of mini-HEP projects which they seem to be struggling with.

Table 2 is the observed timings for the various generators energizing the grid after being instructed to do so by the Control Room [10]. From Table 2, it can be observed that HEP has by far the shortest span in-between being called to start the generator and power from it being loaded onto the grid. This 30 seconds timing is only if the water is already flowing in the penstock pipes. Such a short starting time is very good for the grid because sudden spurts in demand or shut-down of demand can be handled best by HEP dams. Another problem is reliability. Upon calling the ICE or GT power station, operators frequently reply that a set or two is down for maintenance [10].

Table 2
Starting times of generators in Sarawak

Power generator	Starting time
Sejinkat coal power plant (coal)	8 hr
Biawak Internal Combustion engine (ICE)	1 hr
Bintulu gas turbines	45 min
Batang Ai (HEP)	30 sec

Comparatively, the Batang Ai HEP has four sets which are always in running condition. One of the LEA staff who worked in the Batang Ai HEP for over 20 years stated that he has never seen any of the sets go down; they are too simple to fail [10]. They do have Preventive Maintenance (PM) after a long time, for which they will inform the Control Room much earlier [10]. The observation upon a visit to one such PM, is the taking out of the turbine and patching up the small holes on the turbine blades with putty. These holes are caused by stones hitting them or bursting of air bubbles near them. They then put the turbine back [12]. Comparatively in the Biawak ICE, the staff seems to be continuously doing maintenance all year round. They put the pistons which have a diameter of more than six feet (as wide as both hands stretched out) in a large container of kerosene and scrub with their bare hands; breathing the kerosene fumes all the while. They also work in the loudest sound generating environment in Sarawak when such large pistons operate. The staffs are therefore exposed to great health hazards; statistically, these people die between ages 50 to 57 [10]. On the other hand, the operators of Batang Ai dam, have the best health statistics of the whole LEA; probably aided by the clean air environment and lots of fresh fish in the dam lake [12].

III. CONCLUSION

This paper analyses why PV is not optimum especially for non-grid regions of equatorial Sarawak. Figure 2 shows that during the rainy season, the drop in energy harnessing from a PV system is drastic. It is, therefore, imperative that diesel generators are used to back up PV systems in non-grid connected rural villages of Sarawak.

Table 1 indicates that a PV system costs 46 times more than an equivalent MHEP system and after two years when it is time to change the batteries, the PV system will cost 63 times more. The land area utilized by an equivalent 18kV PV system is 2.5 times more than the HEP system. The large land area is a problem not just because of the cost of the land and vegetation destruction of the forest. Vegetation grows very fast at the equator, and it is difficult and therefore expensive to do vegetation clearing in such a large area; in-between all the poles holding up the PV panels. The typical long-handled mechanized grass cutter used in Sarawak will also spray grass or mud particles onto the solar panels.

Table 2 indicates that HEP is the best power source to develop because of the speed at which energy from it can be started up and loaded onto the grid. MHEP is also electromechanically the most reliable energy generator if all the improvements suggested in this paper are incorporated. With diligence in maintaining and changing the batteries every two years, PV power harnessing can work in Sarawak; but it should only be the last option and installed only where there are no river nearby the non-grid connected rural village. Such cases should be very rare because ancient people who start villages will find it hard to survive without a river nearby.

Researchers in Sarawak venturing into PV research will face an uphill battle against those in temperate countries. It is better to focus on perfecting MHEP which has been shown in this paper to be much cheaper and reliable for equatorial regions. And there is a definite need for MHEP research because many regions in rural Sarawak are still not connected to the grid.

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