A Review of Sarawak Off-Grid Renewable Energy Potential and Challenges

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***Abstract*—Sarawak is the largest state in Malaysia, in spite of this, the population of Sarawak is relatively small and 42 percent of that population residing in the rural areas. Consequently, the Sarawak government is facing immense challenges in providing basic need such as electricity to the entire state due to the remoteness and small sizes of these settlements. Although the state produces sufficient amount of power, the cost of connecting these rural and non-rural small settlements to the grid is just impractical. The current energy scenario in Sarawak will be reviewed with a focus on the two reliable renewable energy resources currently being pursued by the Local Electrical Authority (LEA) for rural electrification projects which are the Hydro Power and Solar Energy. The paper will address the technical and localized challenges facing the micro-hydro and solar electric energy generation in Sarawak. The micro hydropower potential in Sarawak is estimated at 10.2MW but is not being fully developed due to difficulty in distinctive design and implementation which requires full participation and support from the local community to make it more economically viable and functionality in long run. In addition, Sarawak also receives a daily solar irradiation of more than 5 KWh/m2 throughout the year and that means huge potential for it to thrive. But design and implementation must be done carefully due to the tropical climate and operating temperature of the components. Ultimately, both renewable energy systems require trained personnel to attend to and involvement of LEA or any appointed agency to provide assistance and coordination are necessary to ensure greater success in rural electrification projects.**

***Index Terms*— Micro Hydropower; Photovoltaic Power; Renewable Energy; Voltage Stability.**

I. INTRODUCTION

In this day and age, electricity is a basic need that everyone must have. But to provide it to everyone in the state of Sarawak, which is the largest state in Malaysia with a total land area of 124,449.51 square kilometers – approximately 37 percent of the total area of Malaysia – is proving to be a daunting task. Furthermore, it was reported about 42 percent out of its 2.66 million population in Sarawak reside in rural areas. Eventually, situations like this provide tremendous challenges to the state government as it involves huge costs to provide electricity to all the rural communities. It is estimated as much as RM8 billion is needed to power up entire Sarawak by 2025 [1]. While remoteness of a settlement imposed a great challenge, the size of the settlement also plays a part in determining whether it is economical enough for them to receive the power. The reason is that the power grid sometimes passes close to small villages along its path. But the cost of stepping down the voltage just to serve these small communities is just impractical. An example is a small indigenous Kenyah Badeng community in Mudung Abun of Belaga District – about 30 households and a population of 200 – where the village is located right in the middle of the Bakun and Murum hydroelectric 275KV power lines that feed the state's main grid.

Therefore, due to these circumstances, LEA would turn to diesel-powered generators and sometimes even to a hybrid diesel-solar system as a short-term solution to power up remote schools, clinics, administrative offices or even small villages for a number of hours daily. In spite of that, the state has achieved greatness in increasing the state-wide electricity coverage from 79.2% to 90.4% in just six years (from 2009 to 2015) should be lauded and the government should uphold its ongoing pledge to focus and increase rural development so that the target of 95% coverage is attainable in 2020 [2].

This paper first outlines the current energy scenario in Sarawak and later the off-grid Renewable Energy (RE) system with particular attention on the potential and challenges of Micro Hydroelectric Power (MHEP) and Solar Energy System (SES) which are currently being implemented to increase electrification coverage in the state.

II. ENERGY SECTOR AND RESOURCES

Sarawak is a large state, and that serves as a big catchment area for its annual estimated rainfall of 5080mm [3] which keeps the many rivers running without low water level. The abundant water resources mean the huge potential for Sarawak in terms of producing clean and reliable renewable energy. The LEA has identified 50 sites with the total hydropower potential of 20GW. But until recently only three sites have been developed and contributed to two-thirds of the total energy resources as can be seen in Table I [2, 4]. The other two main energy resources are coal which contributed 20.4% and natural gas to 11.1% of the total power generation in the state. Sarawak has in its reserve about 1.5 billion ton of coal from five mining sites (about 82% of national total) and 40.9 trillion standard cubic foot of natural gas [5].

Table 1
Energy Generation Scenario in Sarawak

Type	Plant	Capacity (MW)
Hydro	Batang Ai	93
	Bakun	2,400
	Murum	944
Coal	Sejingkat	210
	Mukah	248
	Balingian	600
Gas	Tanjung Kidurong	190
	Bintulu	310
	Miri	78
Mix (Gas, Diesel)	Tun Abdul Rahman	75
Diesel (off-grid)	Scattered in Rural Area	50
	Total	5,198

III. The Need for Rural Electrification

Although Sarawak has surplus power generated, to supply the rural and non-rural small communities remains a great challenge and very costly. The community in these areas is normally of small-scale (less than 50 households) and widely spread out. It is estimated that more than 75% of these villages have 50 or fewer households and 1919 villages with a total of 41,004 households have yet to have access to continuous electricity. Furthermore, 18,038 households are being considered grid connectible but need access and another 12,452 households are being considered too remote and thus not grid connectable [2]. These communities have desired to have continuous electricity for so long, and all the ease that it can bring in assisting their daily chores and much-needed refrigeration for their food, as long enjoyed by the urban dwellers. Besides that, more importantly, these people deserve to have development in infrastructure, improved amenities, increase in job and business opportunities – such as to start a small or medium scale entrepreneurship as emphasized by the government for rural community – to enhance their standard of living [5, 6].

IV. Off-Grid RE for Rural Electrification

Currently, there is two major off-grid RE system being implemented in Sarawak for the rural electrification programs namely the Micro Hydroelectric Power (MHEP) and Solar Energy System (SES). Wind energy generation has been tried but failed miserably as wind resources in the equator are very poor [7].

A. Micro Hydroelectric Power

Although 42% of people in Sarawak stay in rural areas and in small communities, the need for rivers for water supply, the source of food and transportation has made most of them choose to reside in close proximity to the rivers or streams. Consequently, those who inhabited the river upstream or in the highlands will have the advantage of a cleaner source of water and possibility of using that resource to generate electricity through an MHEP system as shown in Figure 1. Through the survey by LEA, the potential of micro hydropower in Sarawak is estimated at about 10.2MW through 104 sites in eight divisions [8] while Table II listed the known site for 27 MHEP with total generated power of 740.3 kW that has been installed throughout Sarawak for the purpose of rural electrification. As can be seen from Table II, not all MHEP construction funding comes from the government.

Figure 1: A MHEP system at a remote village in Sarawak [9].

Figure 2: Centralized Solar Hybrid System in Bario [10].

Table 2
MHEP Installed in Sarawak for Rural Electrification

Division	Village	Year	Capacity (kW)	Funding
Kuching	Kpg. Parang	2011	10	NGOs/ Private
	Kpg. Sapit	2015	6	Community based
Sri Aman	Rh Laroh*	2015	5	Government
	Kpg. Keranggas*	2010	N/A	Government
	Kpg. Sri Stamang 2	2011	18.3	Government
Sarikei	Rh Jawang Janting	2013 to 2015	120	Government
	Rh Michael Jantan			Government
	Rh Lugom Jengging			Government
	Rh Nyaiyang			Government
	Rh Suin Tebru			Government
	Rh Kedit Chundang			Government
Kapit	Rh Unyat Chupong	2015	8	Government
	Rh Suing Ensan	2016	8	Government
	Kpg. Mudung Abun	2010	20	NGOs/ Private
	Long Lawen	2002	10	NGOs/ Private

Division	Village	Year	Capacity (kW)	Funding
	Pa Ramapoh	2015	20	NGOs/ Private
	Kpg. Bario Asal	2009	40	NGOs/ Private
Miri	Long Kerangan	2015	10	NGOs/ Private
	Long Lamai	2013	15	NGOs/ Private
	Long Banga**	2014	320	Government
Lawas	Long Semadoh Naseb	2014	20	NGOs/ Private
	Buduk Nur	2004	7.5	Private
Limbang	Buduk Aru	2006	10	Community based
	Buduk Nur	2008	30	Government
	Buduk Bui	2008	12.5	NGOs & Community based
	Long Langai	2010	15	Government
	Long Rusu	2010	35	Government
		Total	740.3	

* MHEP and PV hybrid
** MHEP with Diesel backup

We shall consider now the voltage and frequency stability issues of a micro hydroelectric generator connected to a rural village load through a transmission line or cable with an impedance $Z = R + jX$. Given a load of $P + jQ$ that is with lagging power factor (hence $+jQ$), the load end voltage of V_L and current I, we have [11]:

$$V_L I^* = P + jQ \tag{1}$$

yielding:

$$I = \frac{P - jQ}{V_L^*} \tag{2}$$

The voltage at the source V_G and load are related by:

$$V_G = V_L + (R + jX)I = V_L + (R + jX)\left[\frac{P - jQ}{V_L^*}\right] \tag{3}$$

As $V_L = V_L^* = V_L$ (in this case):

$$V_G = V_L + (R + jX)\left[\frac{P - jQ}{V_L}\right] = \left[V_L + \frac{RP + XQ}{V_L}\right] + j\left[\frac{XP - RQ}{V_L}\right] \tag{4}$$

The incremental voltages are, therefore:

$$\Delta V_p = \frac{RP + XQ}{V} \tag{5}$$

which causes the voltage variations and instability, and:

$$\Delta V_q = \frac{XP - RQ}{V} \tag{6}$$

is increment that causes variations in the load angle δ and thus the fluctuations in system frequency and stability of the generator. For small values of resistance, XP >> RQ, and these fluctuations therefore largely depend on the active power demand P. If δ is small (as in usually the case in distribution circuits) then:

$$\Delta V_q \ll V_L + \Delta V_p \tag{7}$$

then:

$$V_G = V_L + \frac{RP + XQ}{V_L} \tag{8}$$

and:

$$V_G - V_L = \frac{RP + XQ}{V_L} \tag{9}$$

Hence the arithmetic difference between the voltages is given by:

$$\frac{RP+XQ}{V_L} \tag{10}$$

In a transmission circuit, $R \cong 0$ then:

$$V_G - V_L = \frac{XQ}{V_L} \tag{11}$$

That is, the voltage magnitude depends only on the reactive power demand Q. In case of the lagging power factor load, which we have considered in the above analysis, the load end voltage is smaller than the generator voltage. Thus, low voltages appearing across household loads and street lightning will result in dim lights, slowly rotating fans and high currents drawn from the supply producing excessive heating and burning of wires and appliances. If the generator itself is not generating rated voltage, due to poor exciter operation or governor speeds, the problem is worsened, since this will result in even lower load end voltage. In case of leading power factor load, then the load is $P - jQ$, we note that the load end voltage can become much higher than the generator end voltage, thus leading to high voltage damage of load of a typical village including light bulbs, fan motor, and refrigerator.

B. Solar Energy System

In Malaysia, the annual average daily solar irradiation was from 4.21 kWh/m^2 to 5.56 kWh/m^2. The state of Perlis and Kedah in the northern region of Peninsular Malaysia and a certain area of Sabah and Sarawak are known to receive the highest solar irradiations in Malaysia. All these four states receive more than 5 kWh/m^2/day of solar energy throughout the year [12] which makes it very attractive for solar energy application. The LEA in Sarawak, which has pursued on green technology for rural electrification programs all these years, has recently intensified their effort by installing more solar energy systems to the rural community which are considered not grid connectible in years to come. By the middle of 2016, it was reported the LEA already had 18 PV systems up and running that serves 36 villages, another 13 PV systems to serve 37 villages is still under construction while 9 more PV systems to serve 14 villages are in the planning stage. These systems shall produce 9 to 10 MW of clean energy and are all funded by the government [2]. The rural electrification initiative in Sarawak achieved another milestone on October 25, 2016, when the biggest solar project in Sarawak named the Centralized Solar Hybrid System was officiated in the highland of Bario with a capacity of 887 kW and it serves a cluster of 9 villages with 233 households, shops and administrative offices. Eventually, the connection will be expanded to Arun Layun and Bario Asal to supply electricity to a total of more than 300 households [10]. Figure 2 shows the Centralized Solar Hybrid System in Bario.

V. Off-Grid Re Potential and Challenges

The global Small Hydropower in 2016 has the potential estimated at 217 GW and those already installed are estimated at 78 GW, an increase of 4% compared to 2013. The 78 GW represent 7% of the total global renewable energy generated in 2016 [13]. Meanwhile, the global solar energy generation continues to rise significantly to 227 GW in 2015, which is 10 times the size of cumulative world capacity just a decade earlier [14]. Based on these facts, the LEA has made the right choice for choosing micro hydropower and solar power for rural electrification programs in Sarawak, because it is the green technology that is being accepted and used worldwide.

In Sarawak's scenario, the micro-hydro usage has yet to reach its full potential. The MHEP system is known to be more cost-effective, needing less maintenance and have a longer lifespan as compared to SES [7] which is proven in the 12 out of the 27 MHEP installed has been in operation for more than five years while the MHEP at Long Lawen has been producing electricity since 2002 without fail. Currently, there is only one MHEP-PV hybrid system at Kpg. Keranggas which has been reported failed since 2011. However, a micro-hydro system is not the sort of plug-and-play type of system since each potential site is unique and requires careful designing and implementation in order to be successful. An MHEP system requires a constant water source and are unable to generate electricity during prolonged dry spell so proper water reservoir combine with rationing of water usage are a must. Most HEP also requires a static head of 10m or more which means it is useless in the area with little or no elevation [12]. In the meantime, MHEP setting also requires expensive civil works and control systems but these costs can be cut down by getting help from the community to be involved in the civil construction and using locally manufactured components [7], while maintenance cost can be reduced by training the locals coupled with periodical checking of the system from the LEA or appointed agency. Furthermore, according to JOAS team leader, "strong leadership and organized community are a prerequisite in ensuring the success of an MHEP project" [15].

On the other hand, due to the daily solar irradiation in Sarawak which is considered quite high among the states in Malaysia and almost constant throughout the year, the implementation of solar energy system in Sarawak is growing. The solar energy systems are also easier to install and more suitable for rural area with small elevation or unsuitable water resources for micro hydro power generation. Nevertheless, solar energy systems do have their setback in the equatorial setting despite the benefits mentioned earlier. Due to the tropical climate, high temperatures and humidity cause the termination box to crack and performance of solar panel to drop. Besides, the surface of the solar panel needs constant cleaning from all sorts of debris and growth in order to maintain its performances [7, 12]. Currently, the major concern for the solar energy system is the battery being overused without recharging if the sky were heavy clouded for days and causes the battery to have shorter lifespan [7]. Even so, the problem with recharging the battery and to prolong the battery lifespan can be resolve by equipping the solar energy system with a backup diesel generator. Last, but not least, training the locals would definitely help in maintaining the system and periodical inspection of the system from the LEA or appointed agency will help to keep the system in check.

VI. Conclusion

Sarawak, as the biggest state in Malaysia, still has more than 1.1 million of its population residing in the rural area as reported in 2014, in 2016, it was estimated about 1919 villages with 41,004 households still do not have access to 24-hours/day electricity. The remoteness of the community coupled with typically small population has made the task of extending the connection of the power grid just to serve them is very challenging and uneconomical. Eventually, the state has to come up with multiple schemes such as the Sarawak Alternative Rural Electrification Scheme (SARES) and Rural Power Supply Scheme (RPSS) to pursue the goal of attaining 95% electricity coverage by 2020 [2]. As Sarawak lies in the equatorial region, abundant sunshine and rainfall make it favorable for renewable energy technology such as the micro-hydro and solar power application to thrive in the rural electrification setting. However, careful planning and design must be observed as each energy resource and the potential site has its own barriers to overcome. Micro-hydro system, though very robust and succeeded in the monsoon season and sites with elevation, but performance is compromised in the dryer season or it cannot be implemented in areas which have small or no elevation. On the other hand, the solar energy system – which is known to be less labor-intensive to install, compared to micro-hydro system – do not augur well with the tropical climate which has high temperature and humidity. Alternatively, the solar energy system may be suitable to be implemented in high elevation where temperatures are low and close to the nominal operating temperature of the photovoltaic system. Last but not least, having the LEA or appointed agency to do periodical monitoring and to provide assistance beside continual reskilling and upskilling the locals will definitely help to reduce maintenance cost in the long run and more importantly, to maintain the operation of the system at high efficiency.

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Reference

[1] B. Peter, "RM8 billion needed to power up Sarawak by 2025-Public Utilities Minister," *The Borneo Post*, 2016 Retrieved from http://www.theborneopost.com/2016/09/22/rm8-billion-needed-to-power-up-sarawak-by-2025-public-utilities-minister.

[2] S. Chen, "Rural Electrification in Sarawak, Malaysia: Potential & Challenges for Mini-Hydro & Solar Hybrid Solutions" [Powerpoint Slides], 2016. Retrieved from https://www.eclareon.com/sites/default/files/Presentations/04_chen_shiun.pdf.

[3] Weather Averages and Climate in Malaysia, 2016. Retrieved from

Weather and Climate Website: https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine-in-Malaysia.

[4] R. Shirley, & D. Kammen. "Energy Planning and Development in Malaysian Borneo: Assessing the Benefits of Distributed Technologies versus Large Scale Energy Mega-projects," 2015 Retrieved from University of California Website: https://rael.berkeley.edu/wp-content/uploads/2015/06/ShirleyKammen_ESR_28.05. 2015.pdf

[5] S. Chen, "Hydro Power Development in Sarawak: Opportunities & Challenges. [Powerpoint Slides]," 2015. Retrieved from https://www.slideshare.net/e4sv/kuching-214-sarawak-hydro-development-chen-shiun.

[6] Small & Medium Enterprise (SMEs): Bullet Policies: Enhancing the Performance of SMEs, 2013. Retrieved from Economic Planning Unit (EPU) Website: http://www.epu.gov.my/en/development-policies/small-medium-enterprise.

[7] P. Karunakaran, K. S. L. Alvin, A. N. R. Reddy, "Photovoltaic versus Micro-Hydropower for Rural Non-Grid Connected Areas of Equatorial Sarawak" *Journal of Telecommunication, Electronic and Computer Engineering*, vol. 8, no. 12, pp. 129-132, 2016.

[8] Micro Hydro: Survey of Micro Hydro Potential in Sarawak, 2013. Retrieved from Sarawak Energy Website: https://www.sarawakenergy.com.my/index.php/r-d/micro-hydro.

[9] Admin, "Micro Hydro in Kampung Parang, Borneo Highlands [Blog post]," Aug. 2011. Retrieved from http://bombasticborneo.com/2011/08/microhydro-in-kampung-parang-2/.

[10] "Over 200 Bario Homes Get 24 Hour Solar Power," *The Borneo Post*, Oct. 2016. Retrieved from http://www.theborneopost.com/2016/10/27/over-200-bario-homes-get-24-hour-solar-power.

[11] B. M. Weedy, B. J. Cory, N. Jenkins, J. B. Ekanayake, G. Strbac, *Electric Power Systems* 5th ed., West Sussex, United Kingdom: John Wiley & Sons Ltd, 2012.

[12] H. Borhanazad, S. Mekhilef, R. Saidur, G. Boroumandjazi, "Potential Application of Renewable Energy for Rural Electrification," *Journal of Renewable Energy*, vol. 59, pp. 210-219, 2013.

[13] United Nations Industrial Development Organization and the International Center on Small Hydro Power, "World Small Hydropower Development Report 2016," 2016. Retrieved from United Nations Industrial Development Organization Website: http://www.smallhydroworld.org/fileadmin/user_upload/pdf/2016/WSHPDR_2016_full_report.pdf.

[14] Ren21: Renewable Energy Policy Network for 21st Century, "Renewables 2016: Global Status Report," 2016. Retrieved from Ren21 Website: http://www.ren21.net/wp-content/uploads/2016/06/GSR_2016_Full_Report.pdf.

[15] [JaringanOrangAsalSeMalaysia(JOAS)], *Micro Power, Mega Empowerment*. [Video File], Dec. 2015. Retrieved from: https://www.youtube.com/watch? v=caNyp5HUPXo.