Assessment of Stand-Alone Hydrokinetic Power Supply System with Battery Energy Storage for Rural Electrification

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Abstract- This paper centers around appraisal and plausibility study for energy equalization of stand-alone hydrokinetic power supply system with battery vitality stockpiling in remote rural electrification. This proposed system consists of hydrokinetic turbine that is connected with permanent magnet synchronous generator (PMSG) and power electronics devices. In this paper, proposed site, Dokhtawaddy river which has significant water flow velocity. And it is also near Makyiyay village at Northern Shan State in Myanmar where no the electricity access from national grid is chosen for demand side. In this research work, the all out introduced limit of the proposed system is read for vitality utilization with regular varieties which contributes 25 kW of hydrokinetic turbine and 900Ah of batteries bank. The batteries bank stores the surplus of energy when the load demand is low and discharges again the stored energy to the load when hydrokinetic power is not sufficient to supply the load. The proposed system can meet the load for every hour of the days without interruption. The results show that it is the appraisal of the average daily load requirement and available hydrokinetic power with seasonal variations.

Index Terms- Stand-alone System, Battery Bank, Hydrokinetic Turbine, Generator, Rural Electrification

I. INTRODUCTION

In our country, there are many places that cannot get electricity from national grid. In energy production have become more and more focused on using renewable energy resources such as wind, solar, hydro, biomass and geothermal, etc for rural electrification. Hydropower is by far the main source of electricity in Myanmar, accounting for around 57% of both capacity mix and annual production. Hydrokinetic vitality transformation includes the utilization of the dynamic vitality of waterways, streams, tidal flows or other man-made conduits for age of electric power without appropriating or diverting the progression of the water asset. Unlike traditional hydropower which uses the potential energy possessed by a body of water because of its height ('head'), hydrokinetic devices employ the available energy in the velocity of a stream to turn turbines [1].

The problem statement of this research is that the load center of non-electrified villages is located far away from the substation and the national grid. Therefore, these areas cannot access the electricity until now. The need of reasonable and reliable electricity is very much necessary to develop remote rural areas in developing countries [12]. In these regions, electric power is provided by various options. One is for extending the transmission network of existing system, and receiving power from a distant location. However this is not possible to use practice because of high price transportation lines, their losses, and stability issue that may occur during long range power transmission [11]. The hydrokinetic vitality system just as of other sustainable power source advancements are their asset ward yield powers and their solid dependence on climate. Hence, they can't persistently coordinate the fluctuating burden vitality necessity every single time. The battery operation limits depending on the interaction between the daily variation of hydrokinetic source and the dissimilarity of load demand pattern.

The contrast between renewable power generation and burden request are fundamental difficulties experienced. From the interest side administration perspective, energy from the renewable source can be stored when the generation is higher than the demand or discharged when the generation is lower than demand.

In this paper, for the reason for appraisal, the Makyiyay town in Myanmar is chosen, which is situated at 22.02 north latitude and 96.56 east longitude in the Naungkhyo Township, Northern Shan State in Myanmar. And it is also near Dokhtawaddy river which has significant water flow. In this case, we consider a stand-alone system composed of a hydrokinetic source, battery and converter systems. Based on this evaluation setup, we derive the daily and monthly load profiles for the household data from the village, and obtain the daily and monthly water velocity profiles from the climate data. Then, the advantages of the proposed system are analyzed power balance condition through simulations using the MATLAB/SIMULINK.

The rest of this paper is sorted out as follows. The assessment of demand for proposed village is presented in section II. In section III, supply side appraisal for proposed framework. The stand-alone hydrokinetic power supply system with battery storage system is presented in section IV. The simulation results and discussion are given in section V, followed by the concluding remarks in section VI

II. DEMAND SIDE ASSESSMENT

In this paper, for the purpose of evaluation, the Makyiyay village in Myanmar is selected, which is located at 22.02 north latitude and 96.56 east longitude in the Naungkhyo Township, Northern Shan State in Myanmar. Based on this evaluation setup, primary data on energy requirement were obtained by structure interview from stakeholders in the village like village executive officer, school leaders, religious leaders and other villagers. We derive the daily and monthly load profiles for the household data from the village. The power burdens are separated into two gatherings from living arrangements and from public offices. The residences group consists of 35 households in the low-, medium-, and high-income ranges. The electricity demand in the low income range is limited to the requirements for lighting and TV, and the annual growth rate of electricity consumption is small. The households in the medium-income range may additionally use electric fans, and their annual growth rate of electricity consumption is increasing rapidly. The households in the high-income range may use refrigerators. The communal facilities include schools, monastery, rural health clinic, and street lighting. And then, there are three seasons in Myanmar such as summer season from February to May, rainy season from June to September and winter season from October to January. Although all electric loads are used in summer, electric fan load is reduced in rainy and winter. The power utilization of every part in Table I is evaluated by accepting the hourly use example of the apparatuses for each heap part.

Table I. Load Components for Makyiyay Village

Components		Nos	Power Consumption (kWh/day)		
			Summer	Rainy	Winter
Residence	Low income	10	65.200	65.200	65.200
	Medium income	15	161.663	154.203	149.063
	High income	10	137.274	129.814	128.874
Community	School	1	7.418	7.418	7.418
	Monastery	1	28.150	26.658	26.350
	Health Clinic	1	24.478	24.478	23.518
	Street	5	2.400	2.400	2.400
Total Power Consumption			426.583	410.171	402.823

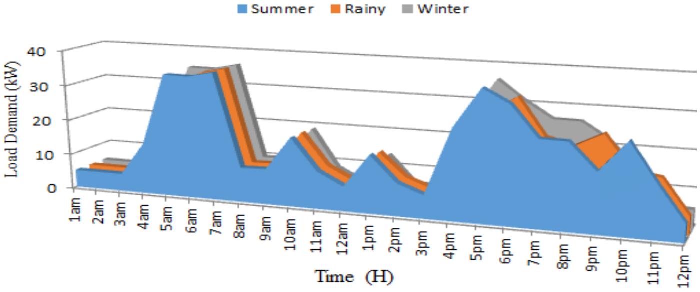

Fig. 1 Daily load profile for the Makyiyay village

In Fig. 1, the average, minimum and peak load demands are 17.77 kW, 5.03 kW and 36.104 kW in summer season, 17.09 kW, 5.03 kW and 35.987 kW in rainy season. and are 16.79 kW, 5.03 kW and 36.104 kW in winter season.

III. SUPPLY SIDE ASSESSMENT

The location is a bridge, the Dokhtawaddy bridge acrosses the narrowest of river, which has the maximum local flow velocity as shown in Fig.2. Therefore, the available kinetic power is the highest in that area.

Fig. 2 Dokhtawaddy Bridge View (Source-Google)

A. Flow Velocity Estimates in the Region

The water release of objective site anticipated relies upon estimated information on 20 April 2018 as appeared in Table II and month to month mean records from Department of Meteorology and Hydrology for a time of three years as appeared in Fig. 3. The predicted monthly discharge is presented in Table III. and illustrated in Fig.4.

Table II. Measured Data of Proposed Site on 20 April 2018

Parameters	Specification
Velocity	3.1 m/s
Depth	2 m
Width	33.22 m
Area	66.44 m^2

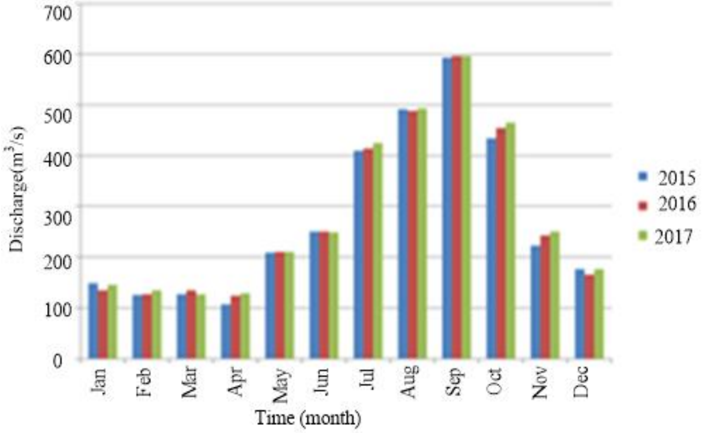

Fig. 3 Monthly mean discharge of Dokhtawaddy River

Table III. Predicted Monthly Discharge (m3/s)

Month	Minimum	Maximum	Average
January	146.320	167.40	154.22
February	136.400	145.08	141.56
March	124.000	137.02	129.06
April	124.000	124.00	124.00
May	124.000	231.26	136.80
June	201.500	241.80	226.54
July	207.080	254.20	240.02
August	207.080	252.34	237.98
September	201.500	251.10	235.12
October	217.620	254.20	242.62
November	127.100	160.58	141.64
December	133.300	252.34	177.17

Estimated water velocity using the volumetric flow rate expression:

$$V = \frac{Q}{A} \tag{1}$$

Where Q is the discharge, A is the cross-sectional area and V is the flow velocity. Cross-sectional region of the locale is displayed in Table II. Flow velocity for region was obtained by application of Eq. (1). Individual stream speeds inside the engaged locale are displayed in Table IV and Fig.5. The minimum and maximum velocities with seasonal variations are 3.5 m/s in June of rainy and 3.01 m/s in February of summer as shown in Fig. 4. The minimum average velocity is about 3 m/s in February of summer.

Table IV. Monthly Mean Velocity (m/s)

Month	Minimum	Maximum	Average
January	3.05	3.20	3.10
February	3.01	3.03	3.01
March	3.00	3.10	3.03
April	3.05	3.10	3.09
May	3.04	3.30	3.10
June	3.07	3.50	3.20
July	3.07	3.40	3.10
August	3.06	3.25	3.14
September	3.03	3.30	3.15
October	3.05	3.20	3.11
November	3.00	3.08	3.03
December	3.00	3.20	3.05

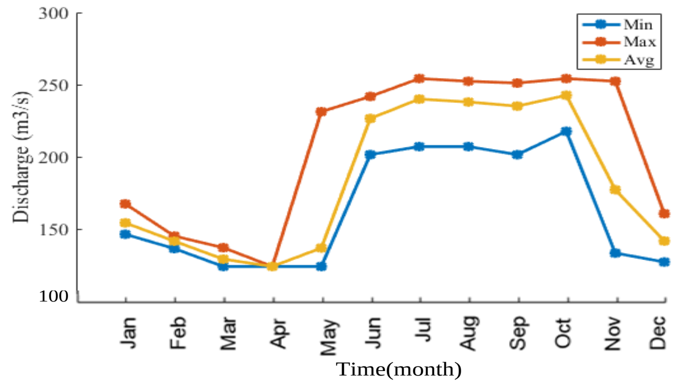

Fig. 4 Monthly Discharge of Dokhtawaddy River

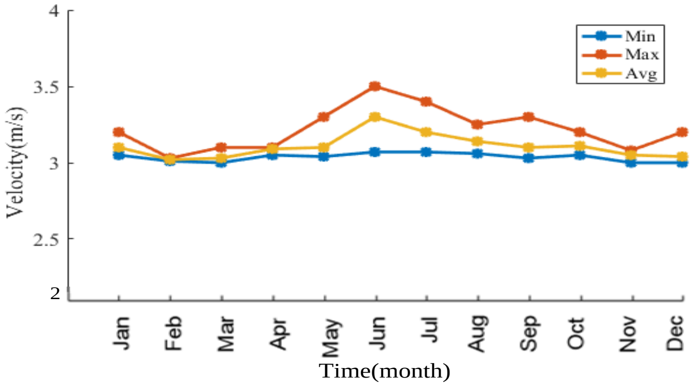

Fig. 5 Monthly Velocity of Dokhtawaddy River

B. Hydrokinetic Power

In the proposed system, vertical axis straight blade hydrokinetic turbine is used. The turbine captures a portion of the power in the water that passes it, P_m:

$$P_m = 0.5\,\rho\,C_p\,A\,V_w^3 \tag{2}$$

Where P_m is the mechanical output power of the hydrokinetic turbine (Watt), ρ is the water density (kg/m^3), A is the swept area (m^2), C_p is the power coefficient of the hydrokinetic turbine and V_w is the water speed (m/second). And after that the generator yield power can be determined by duplicating the effectiveness of generator and the mechanical yield intensity of the hydrokinetic turbine. The estimated hydrokinetic powers that can be harvested in the region are presented in Tables V–VI and Figs. 6–7 below. The minimum monthly average powers with seasonal variations are 22.26 kW in February of summer, 25.27 kW in August of rainy and 22.68 kW in November of winter.

Table V. Available Power from the Turbine (kW)

Month	Minimum	Maximum	Average
January	25.53	29.49	26.87
February	24.54	25.06	24.74
March	24.3	26.81	25.11
April	25.53	26.81	26.73
May	25.28	32.34	27.21
June	26.04	38.58	32.52
July	26.04	35.37	29.52
August	25.78	30.89	28.08
September	25.03	32.34	28.24
October	25.53	29.49	27.28
November	24.30	26.29	25.21
December	24.30	29.49	25.43

Table VI. Output Power from the Generator (kW)

Month	Minimum	Maximum	Average
January	22.97	26.54	24.18
February	22.08	22.55	22.26
March	21.87	24.12	22.60
April	22.97	24.12	24.05
May	22.75	29.10	24.49
June	23.43	34.72	29.26
July	23.43	31.83	26.57
August	23.20	27.80	25.27
September	22.52	29.10	25.41
October	22.97	26.54	24.55
November	21.87	23.66	22.68
December	21.87	26.54	22.80

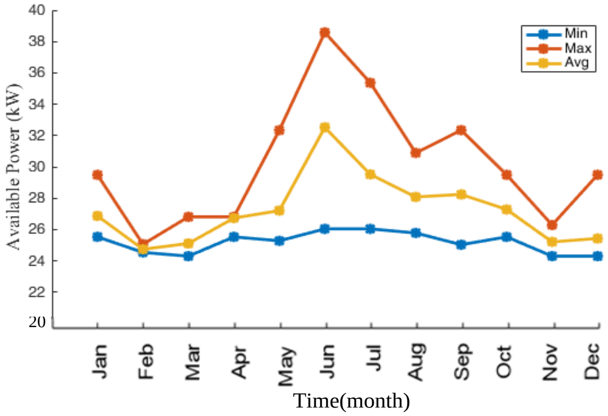

Fig. 6 Monthly Available Power from Target Area

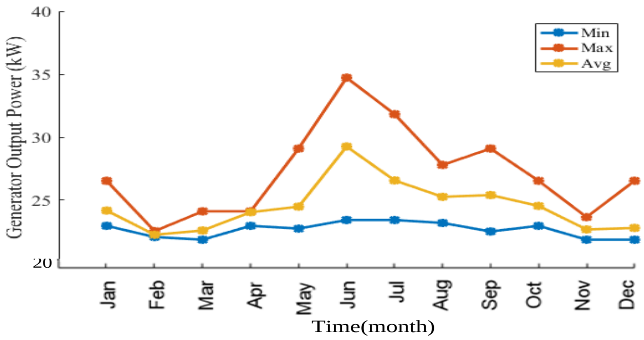

Fig. 7 Generator Output Power from Target Area

The monthly hydrokinetic power of seasonal variations can be sufficient to the monthly load power consumption. This is presented in Table VII. However, the peak load demands are 36.104 kW in summer season, 35.987 kW in rainy season and 36.104 kW in winter season as mention in section II. Therefore, the hydrokinetic power can not sufficiently to supply when load demand exceeds the available power from the system for some hours in day. At this time, hydrokinetic power supply plus with energy storage systems as battery, super capacitor and dump load can supply. The battery bank stores the surplus of energy when the load demand is low and discharges again the stored energy to the load when hydrokinetic power is not sufficient to supply the load.

Table VII. HKE and Load Power Consumption with seasonal variations (kWh/month)

Time	Summer (February)	Rainy (August)	Winter (November)
HKE (kWh/month)	14962.752	18802.368	16336.08
Load Demand (kWh/month)	11944.324	12715.301	12084.69

IV. STAND-ALONE HYDROKINETIC ENERGY SUPPLY SYSTEM WITH BATTERY STORAGE

The hydrokinetic turbine is connected with the permanent magnet synchronous generator to extract electrical energy from river. The power circuit topology of the proposed variable speed stand-alone hydrokinetic vitality supply framework with battery storage system is appeared in Fig. 8.

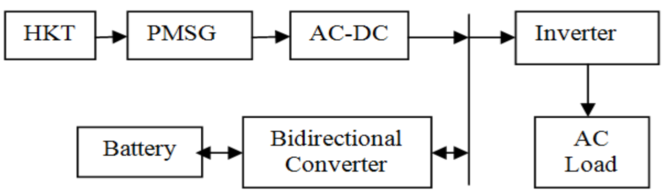

Fig. 8 Schematic Diagram of Proposed System

The framework comprises of hydrokinetic turbine, lasting magnet synchronous generator (PMSG), which is straightforwardly determined by the hydrokinetic turbine without utilizing a gearbox, a solitary switch three stage mode rectifier which comprises of a three stage diode connect rectifier, DC-DC help converter and DC-DC bidirectional converter. A three phase voltage source inverter connected to the load through LC filter. A detail of the control system has been avoided here to simplify the system.

A. Hydrokinetic Turbine

Hydrokinetic turbines share numerous similitudes with wind turbines in terms of physical standards of activity, electrical equipment, and variable speed capacity for ideal vitality extraction. Differences relate to the higher density of water, the presence of water surface, turbulence, and predictability of the resources. The first step to design a hydrokinetic turbine system (HTS) is to decide whether to use horizontal turbine system or vertical turbine system. In the proposed system, vertical axis straight blade hydrokinetic turbine is used.

B. Hydrokinetic Turbine Generator

In order to reduce costs, and to have the option to depend on privately made innovation, lasting magnet generator can be utilized. The magnets enabled the speed of age to be diminished, and brought down the expense of the gear, which itself could be adjusted to be a stream turbine rotor and at last, tried and fabricated. Because of lower age speed, gearboxes or generators with high number of poles can be utilized.

C. Sizing of Battery Bank

System battery size can be calculated by using the following equations. The required daily average energy demand has already been calculated in section 2. The selected storage day should be 1 day at least. Maximum depth of discharge is based on the selected battery and it is 80 percent of Lithium-ion battery.

The estimate energy storage,

$$E_{est} = E_{rd} \times \text{the number of autonomy days} \tag{3}$$

The safe energy storage,

$$E_{safe} = \frac{\text{the estimate energy storage}, E_{sd}}{\text{maximum depth of discharge}, D_{dish}} \tag{4}$$

The total capacity of battery bank in ampere-hours,

$$C_{tb} = \frac{\text{the safe energy storage}, E_{safe}}{\text{the rated dc voltage of one battery}, V_b} \tag{5}$$

And then number of parallel batteries and series batteries will be calculated as follow:

$$\text{The total number of batteries, } N_{tb} = \frac{C_{tb}}{C_b} \tag{6}$$

$$\text{The number of batteries in series, } N_{sb} = \frac{V_{dc}}{V_b} \tag{7}$$

$$\text{The number of parallel batteries, } N_{pb} = \frac{N_{tb}}{N_{sb}} \tag{8}$$

Therefore, the required battery capacity is 1008 Ah. The suitable design with system is Lithium-ion battery model. Its capacity is 300 Ah, 12 V and 80 percent discharging. There are 150 numbers of batteries in this system which composed of 3 parallel strings with each including 50 batteries in series. The battery is displayed as a nonlinear voltage source whose yield voltage depends not just on the current yet in addition on the battery condition of charge (SOC), which is a nonlinear capacity of the current and time. The month to month greatest estimations current and time of pinnacle burden request, HKP and battery vitality stockpiling framework is exhibited in Table VIII. According to Table VIII, the maximum and minimum power values of charging are 21.539 kW in July and 15.06 kW in November. Moreover, the maximum and minimum values of discharging power are 13.014 kW in November and 6.719 kW in June. In this exploration work, the absolute introduced limit of the proposed framework is assessed for vitality utilization with occasional varieties which contributes 25 kW of hydrokinetic turbine and 22.5 kW of batteries bank.

Table VIII. Monthly Maximum values of PLD, HKP and BESS

Month	Peak Load (kW)	HKP (kW)	Total Charging Time (h)	Max: Charging Value (kW)	Total Discharging Time (h)	Max: Discharging Value (kW)
January	36.104	24.18	16	18.396	8	12.681
February	36.104	22.26	15	17.239	9	13.835
March	36.104	22.6	15	17.567	9	13.505
April	36.104	24.05	17	19.029	7	12.045
May	36.104	24.49	17	19.463	7	11.494
June	35.987	29.26	18	21.238	6	6.719
July	35.987	26.57	18	21.539	6	9.418
August	35.987	25.27	18	20.249	6	10.708
September	35.987	25.41	18	20.386	6	10.688
October	36.104	24.55	16	19.520	8	11.554
November	36.104	22.68	16	15.060	8	14.014
December	36.104	22.8	16	17.656	8	13.418

V. RESULTS AND DISCUSSION

In this paper, genuine burden and water speed have been utilized as input information to assess the presentation of the framework submitted to the ideal vitality the board framework. It has been collected for a day in seasons where the velocity is the lowest compared to the other days of seasons. The sizing of HKT and Battery bank is based on a load demand and water velocity of proposed site. The parameters of this system are shown in Table IX.

Table IX. Parameter of Hydrokinetic Turbine, Generator and Battery

Parameter	**Symbol**	**Rating**	**Unit**
Rated water speed	V_{rated}	3.0	m/s
Cut-in water speed	V_{cut-in}	1.5	m/s
Cut-out water speed	$V_{cut-out}$	4.5	m/s
Blade diameter	D	3	m
Blade height	H	1.5	m
Power coefficient	C_p	0.4	-
Swept area	A	4.5	m^2
Turbine rated speed	N	60	rpm
Generator rated power	P	25	kW
Frequency	f	50	Hz
Pole pair	p	50	-
Stator phase resistance	R_s	1.144	ohm
Armature Inductance	L	0.00448	mH
Lithium-ion battery system rated voltage	V	600	V
Rated capacity	C_b	900	Ah
Initial SOC	SOC	80	%
Cut-off voltage	$V_{cut-out}$	450	V
Full charge voltage	$V_{full-charge}$	680	V
Require battery capacity	C_{tb}	1008	Ah
Number of parallel batteries	N_{pb}	3	nos
Number of series batteries	N_{sb}	50	nos
Total number of batteries	N_{tb}	150	nos

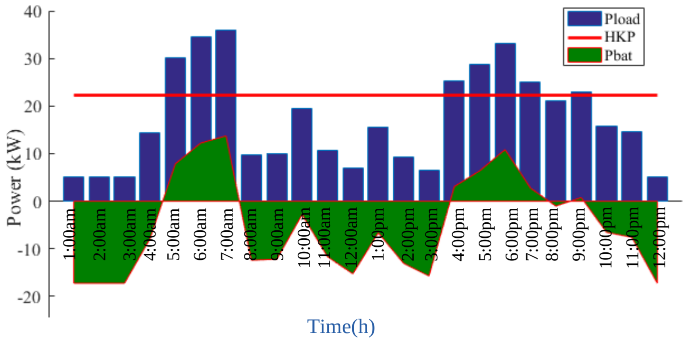

Fig. 9 Hydrokinetic Power, Load Demand and Battery Storage during one day of summer

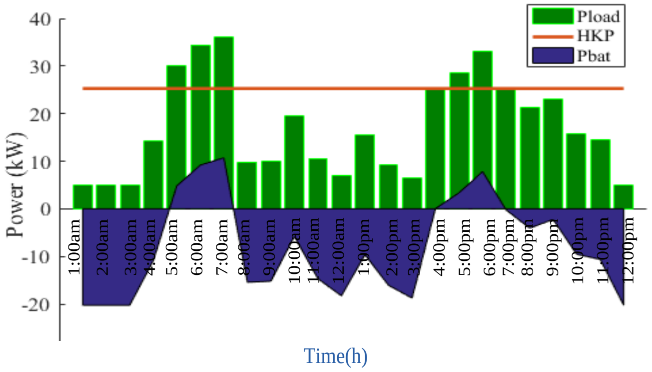

Fig. 10 Hydrokinetic Power, Load Demand and Battery Storage during one day of rainy

The battery bank stores the surplus of energy when the load demand is low and discharges again the stored energy to the load when hydrokinetic power is not sufficient to supply the load. The chose burden request arrives at a pinnacle request of 36.106 kW in summer.

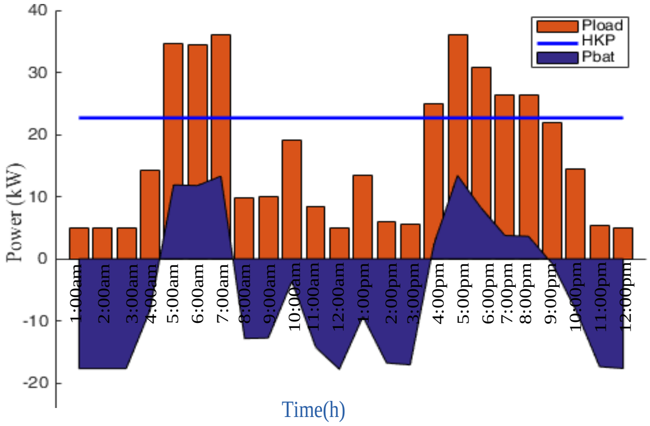

Fig. 11 Hydrokinetic Power, Load Demand and Battery Storage during one day of winter

Hence, the proposed framework must have the option to sufficiently react to this interest. The hydrokinetic power, load demand and battery storage during one day of seasonal variations and battery charging and discharging current were presented in Fig. 9, 10 and 11. The hydrokinetic powers were 22.26 kW, 25.27 kW and 22.68 kW and then peak load demands were 36.104 kW in summer season, 35.987 kW in rainy season and 36.104 kW in winter season. In negative section of curves are showing the charging of battery bank, and in positive section is discharging of battery bank. The battery bank can be charged maximum powers 17.23kW, 20.24kW and 17.65kW from excess energy. And then, the battery bank discharged maximum power 13.73kW, 10.717kW and 13.424 kW again the stored energy to the load when the hydrokinetic power is not sufficient to supply the load. Thus, according to the comparison of hydrokinetic power, load demand and battery bank with three seasons, the HKP source as 25 kW at 3m/s water velocity and 900Ah of battery bank were evaluated

VI. CONCLUSION

In this paper, a selected village in Myanmar is designed the economic feasibility of a stand-alone system considering the specific local conditions and resource availability for the village. This paper is studied of the energy balance of hydrokinetic power supply with battery storage system in addition to design consideration. The monthly hydrokinetic power of seasonal variations can be sufficient to the monthly load power consumption. However, the peak load demands were 36.104 kW in summer season, 35.987 kW in rainy season and 36.104 kW in winter season. Therefore, the hydrokinetic power can not be sufficiently supplied when load demand exceeds the available power from the system for some hours in day. In this research work, the all out introduced limit of the proposed framework is chosen by 25 kW of hydrokinetic turbine and 22.5 kW of batteries bank for pinnacle burden requests (36.104 kW, 35.987 kW and 36.104 kW) with regular varieties.. Moreover, when the load demand increases, the hydrokinetic turbine will be needed to install more. As seen from the results, the system can be supplied for enough power to consumers who live in Makyiyay village without interruption.

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