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Solar and Wind Hybrid Power for an Extremely Remote Mobile Base Station

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There is a challenge to provide reliable cellular mobile service at an extremely remote location where a reliable power supply is not available. The main causes of service interruption are failure of transmission backhaul links and power supplies. This paper presents a solution utilizing a hybrid of solar and wind power systems with a portable generator to provide reliable power for a mobile base station located behind the Himalayas of south Asia. The design is based on the local mobile subscribers with 350 capacities with 51mE per subscriber traffic and the peak load capacity of 750 W. The meteorological data including solar sunshine hours and hourly wind speeds are taken for a site in Mustang district at 3444 m altitude. The power consumption pattern of a mobile base station depends up on the traffic pattern of the mobile users. The cost of the hybrid system is also estimated as $81,512.04 Canadian dollars.

Nomenclature

A	= *Swept rotor area in* m^2
B_c	= *Battery Capacity in Ampere Hours*
I_c	= *Regulator Capacity in Ampere*
m	= *Length in Meter*
N_s	= *Number of solar in series connection*
P	= *Power Consumption of the telecommunications Equipment or Load in watt*
P_{act}	= *Power Actual in Watt*
P_{max}	= *Maximum power output*
P_w	= *Wind Power in Watt*
V	= *Speed of the wind in meters/second*
V_s	= *System rated Voltage*
ρ	= *Air density in kg/m3*
M_c	= *Solar Module Capacity in AH*
I_{mp}	= *Maximum current of solar module*
x	= *Number of daily sunshine hours*
V_s	= *System Voltage*
B_c	= *Battery Capacity in AH*
D	= *Number of days of autonomy*
d	= *Depth of discharge (0.8)*
I_c	= *Capacity of Regulator in Ampere*
I_{mp}	= *Maximum current of solar module in Ampere*
N_p	= *Number of solar in parallel connections*
W	= *Power in Watt*

I. Introduction

The twenty first century is the era of electronic media. Cellular mobile is one of the most popular devices in the world. Mobile device is also popular in the rural area of any nations. The reliability of the network is the challenge for extremely remote locations. This study considers an extremely remote site from south Asia; behind the Himalayas mountain range of Nepal. Nepal has an area of 147,181 km^2 and located in between the geographical location of latitudes 26^{0}22'N to 30^{0}27'N and longitudes 80^{0}04'E to 88^{0}12'E. Elevation ranges from near sea level at the northern edge of the Indo-Gangetic plains to high Himalayan ranges in the north with altitudes up to peak of the world 8,848 m (Panigrahi at el., 2008).

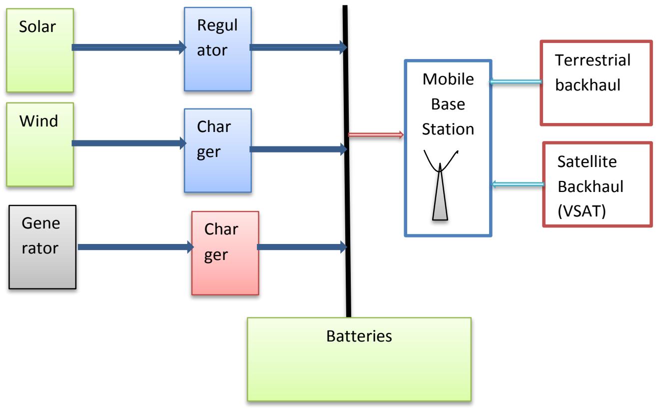

Figure 1. A typical model of Hybrid Power for Mobile BS

The cellular mobile network consists of major two systems: radio/switching system and power system. Radio/switching system consists of hand held terminal, base stations and controllers and mobile switching center. Any mobile base station needs to connect with Base Station Controller (BSC) through some transmission backhaul links which can be optical or microwave or satellite or any combination of them (Acharya et al., 2010). These BSCs are connected with Mobile Switching Center (MSC) for routing and charging of any calls. The reliability of backhaul links depends up on the type of link. Power system consists of devices to supply the energy to the electronics to run the mobile stations. It was observed that most of rural mobile base stations are out of order because of the link failures and power failures. The most of causes of link failures are due to power failure at the site. It is more challenging to deploy cellular mobile Base Trans-receiver Stations (BTSs) in extremely remote location of any country at an altitude of 3444 m behind the Himalayas. Once BTS is deployed, the most challenging part is to feed the reliable power source to the station. In these areas, there are few local micro-hydropower plants which are unreliable. Most of the turbines are operated only at the night time for few hours because they use river water for farming in day time and need to collect water to build enough head at the mid night. Most of them produce full capacity electricity only in rainy season. Cellular mobile service providers cannot rely on local electrical power supply. Hence, alternative means of reliable power supply for the mobile base station is required so that it can operate the system for 24 hours a day and seven days a week (Acharya et al., 2011). For this, reliable power provisioning is very important. At such sites, solar could be one option but during the winter, solar panels are covered by snow and sunshine hours are limited because of the surrounding high peaks. Alternative could be the wind power but the continuous flow of wind is not found (Kanel et al., 2001) so the combination of solar and wind power could be a solution for the continuous operation of the mobile services. Boost charging of batteries is also recommended through the portable generator. The typical model of the proposed hybrid is shown in the Figure 1. For the reliability of the transmission backhaul link, satellite and microwave links are proposed to connect to the mobile base station for this site (Acharya et al., 2010).

II. Fundamental Engineering and Scientific Principles

Because of the availability of enough sunshine hours and average wind speed, hybrid solar and wind based power system with reliable battery backup is proposed to provide the reliable cellular mobile service to the remote users.

2.1 PV Solar Energy:

In the most of the developing countries, solar power is one of the important sources of energy and used for rural electrifications. The insolation is strong in the solar belt and the lengths of the sunshine hours are enough to generate the electricity. The intensity of insolation changes with the rotation and revolution of the earth. In summer, long sunshine hours are available on the south Asia. In Africa and South-East Asia there is usually significant solar insolation to be utilized. According to NASA, many developing countries are located in this sunlight rich region.

Photovoltaic (PV) is a technique for generating electrical power from sun light due to flow of electrons on semiconductors. This technique uses solar panels with number of solar cells. In the market, common available solar cells are 36, 48 and 72. One hour of full sun provides about 1000 Wh/m^2 of energy. The efficiency of the PV technology varies based on the type of material used. Mono-crystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride and copper indium gallium selenide are commonly available material for manufacturing the solar cells (Joshua Pearce, 2002). The efficiency of mono-crystalline silicon, polycrystalline silicon and amorphous silicon are 14-17%, 12-13% and 5-7% respectively in production phase. Solar power has a big potential in energy generation in off-grid areas of north to south parts of Nepal.

2.2 Wind Energy

Wind is another form of renewable energy which is also generated by solar energy. Winds are produced by numerous factors such as the sun heating, the atmosphere, unevenly irregularities in the earth's surface and the rotation of the earth. The irregularities in the earth’s surface are created by variable terrain, vegetative cover and water bodies (for example oceans, seas and lakes) and they impact the wind flow patterns. The wind is gathered by the wind turbines and generates electricity. There are several factors that affect to the power gained from windmills. The wind power is calculated by using eqs.1, 2 and 3(Grogg K, 2005):

$$P_w = \frac{1}{2}\rho A V^3 \qquad (1)$$

$$P_{max} = 0.59 P_w \qquad (2)$$

$$P_{act} = P_{Max} P_p \qquad (3)$$

Where,
P_w = *Wind Power in W*
P_{max} = *Maximum power output in W*
ρ *(rho)* = *Air density (kg/m^3), 1.225 kg/m^3 at sea level, less in higher altitudes*
A = *Swept rotor area (m^2)*
V = *Speed of the wind (m/s)*
C_p = *Power Coefficient*
P_{act} = *Power Actual*

From the above equations, we can conclude that doubling the wind speed, the wind’s power raises by eight times. The real extractable wind power depends on several factors such as type of machine, the rotor, the blade and the frictional losses. Theoretically, a maximum of 59.3% of the power from the wind can be extracted. In addition, wind power also depends up on the daily and seasonal wind cycles, wind direction and obstacles. Based on the information provided by NASA, it shall be noted at height of 50 m, the wind potential increases also in the lands. Thus, wind energy could also be considered as a power resource in landlocked countries like Nepal by focusing on large wind mills. Location specific research and accurate wind speed data are essential when wind is considered as the main energy source.

III. Literature Review

Mustang of Nepal is a beautiful and important place for trekkers. In Figure 2, the three different colors in the map shows cellular mobile signal by three different base stations proposed at three different locations of Mustang. Although Nepal has a high potential for wind energy, only insignificant amounts of energy have been harnessed so far.

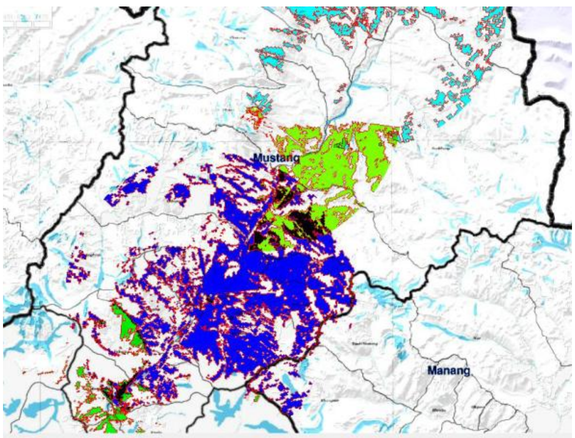

Figure 2. BTS Sites with Mobile Coverage (Mustang District)

The wind could be a very good alternative source of energy in remote and rural areas of Nepal where a national electrical grid will not be built in the foreseeable future. Because of low and variable wind speeds in this area and heavy snow-fall in winter, neither wind nor solar alone can fulfill the requirements. However, long summer days and windy winter conditions may make a wind/solar combination attractive (Motorola, 2007). When wind speeds are within the range 5-6 m/s at any rural locations of BTS, Wind-Solar hybrid systems can be considered as an ideal alternative (Panigrahi at el., 2008). The energy generated by such hybrid power is environmentally friendly and non-polluting. Solar energy and wind energy can complement each other that is whenever sunlight is there solar energy is there for battery charging, whereas when there will be wind speed even in the night energy generation will be continuous to charge the battery. Hence, battery charging process is continuous all the time. During the raining season, there will be much cloudy days all power backup can be maintained by the wind power. All the morning, there will not be enough wind speed; solar power will maintain the energy poll for the mobile systems. Therefore, the hybrid system with solar and wind utilizes the optimum of both resources and can deliver a constant power supply for sustainable development (Panigrahi at el, 2008). With the backup of generator, the reliability of the system can be guaranteed, even though use of generator is minimum. The hybrid system should be designed in such a way that minimum use of generator should be considered (Pragya at el., 2007).

Even though alternate power solutions are not commonly used in mobile telecommunication systems today, they are actively evaluated for remote and isolated areas worldwide. The better network services of mobile operator are possible by using reliable power supply using renewable based hybrid systems in rural areas where electrical grids are not available (Pragya at el., 2008). Although the net present cost is high, the running and maintenance cost are low as compared to the diesel generator power solution. Its' payback period is around 15 years (Pragya at el, 2010).

In the rural area of Mustang, the number of mobile users is low. During a trekking season more users can be expected. The energy consumption of cellular networks can be reduced by decreasing the energy consumption of BTS sites and also by minimizing the number of BTS sites which may varies from 0.5 W to 10 kW or higher (Jyrki, 2007). Low power consumption with single or two trans-receivers (TRX) with Omni directional antenna BTS are recommended (Allabaksh, 2010). The base station equipment with 3kW power consumption needs a wind generator output power of 8 kW, a photovoltaic output power of 7.4kW and 177kWh storage batteries for a system operation rate of 100% in Yonaguni Island of Japan with non-stop operation (Shiego at el., 2004). Nepal Telecom is using BTS with S666 or S444 configurations for urban area, S444 or S222 configuration for suburban area, S111 for rural at hilly area and Omni with single TRX O1/O2 for extremely remote area of Nepal. Typical average power consumption as indicated by the manufacturers is summarized in Table 1 (NTC, 2010).

Table 1: Typical Power Consumption of GSM BTS (NTC, 2010)

Types of BTS	Area to be served	Typical Power Consumption in W	Number of Mobile Users at 35mErl traffic	Power Consumption of Typical Cellular Backhaul links in W
S666	Dense City	3500	3000	2000
S444	City	2000	2000	1500
S222	Suburban	1500	1000	1000
S111	Accessible rural (Hilly)	1000	500	750
Omni O2	Remote (Mountainous)	500	350	250
Omni O1	Extremely remote (Mountainous)	300	300	280

Equations 4, 5, 6 and 7 are used for the sizing of solar, battery, regulator sizing (Kanel et al, 2001):

$$M_c = \frac{I_{mp}X}{1.25} \qquad (4)$$

$$P_d = \frac{24P}{V_s} \qquad (5)$$

$$B_c = \frac{P_d D}{d} \qquad 6$$

$$I_c = \frac{I_{mp}N_p}{0.8} \qquad 7$$

Where,
Mc = Solar Module Capacity in AH
Imp = Maximum current of solar module
x = Number of daily sunshine hours
Vs = System Voltage
Bc = Battery Capacity in AH
D = Number of days of autonomy
d = Depth of discharge (0.8)
I_c *= Capacity of Regulator in Ampere*
I_{mp} *= Maximum current of solar module in Ampere*
N_p *= Number of solar in parallel connections*

Battery bank is used as a storage system and it also maintains constant voltage across the load. The battery bank consists of series and parallel connections. The energy stored in the deep cycle batteries can then be used directly to power DC loads. Deep cycle batteries are recommended for rural BTS systems. To ensure enough reserve capacity to power the BTS without running additional generator, proper sizing of deep cycle battery bank is required.

The calculation of the number of solar panels, battery capacity, regulator sizing and the capacity of wind power generator was not carried out by any researcher in the past for a mobile base trans-receiver station (BTS) at extremely remote part at high altitude. This study tries to estimate these values considering uninterrupted power supply to mobile base station using microwave and VSAT as cellular backhaul at 3444m in Mustang of Nepal.

IV. Methodology

To determine the size of a small wind turbine generator, number of solar panels, battery capacity, regulator capacity and the portable generator, following methodology has been opted. Sunshine hours and solar isolation data are collected for a specific location of Mustang at latitude of 28.805°N and longitude of 83.744°E. For installation of PV arrays on structure, necessary space, orientation, slope and potential shading objects are checked from a topographic maps and during the field survey. Similarly, wind speed data for specific location at 20m height is collected. Wind power potential is calculated using a 7.5 kW BWC EXCEL-R/48 simulator and formulae stated above. The typical power consumptions of the practical cellular mobile micro BTS with O2 antenna are taken from the user manual of the manufacturer. Capacity of wind turbine, solar PV system, battery banks and converter are estimated. Small portable generator is determined so that it can charge the batteries in 10 hours. Weather data are important for determining the sizing of wind and solar system for any particular site. Here, the wind and solar energy resources data are taken from NASA and field survey data for Mustang, Nepal at 28.805°N and 83.744°E and Altitude 3,444m and shown in Table 2 (NASA, 2011). In summer, solar hours are longer than in winter season while in rainy and winter seasons, cloud coverage last as high as for a week. For the wind power calculation, Weibull distribution, wind shear exponent, anemometer height, tower

Table 2: Solar and Wind Speed data from NASA and field survey

Month	Relative humidity	Daily solar radiation - horizontal	Average Sunshine hours/day	Wind speed NASA	Wind Speed from field
	%	kWh/m^2/d	Hours	m/s	m/s
January	48.5	3.99	4.5	4.0	6.95
February	51.6	4.57	4.5	4.1	7.4
March	46.9	5.54	5.5	4.2	7.7
April	50.7	6.24	6	4.2	7.55
May	68.0	6.48	6.5	4.1	6.55
June	82.0	6.03	5	3.4	5.6
July	89.7	5.32	5	2.6	4.7
August	89.7	5.01	5.5	2.5	4.8
September	86.8	4.81	6.5	2.7	4.7
October	73.9	5.07	6	3.5	5.9
November	53.6	4.48	5.5	3.7	6.8
December	42.6	3.98	4.5	3.9	6.65

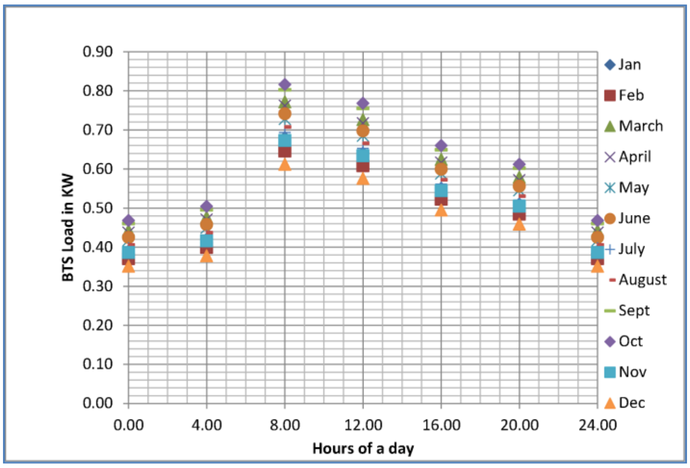

Figure 3: Load Pattern of BTS

height and turbulence factors are considered as 2, 0.18, 10m, 10m and 15% respectively. The daily wind speed at an interval of 1 hour is measured for one year. During the observation, it is found that wind speed from the mid night to 11 am is not as high as enough to produce the wind power. The wind speed from 11 am to mid-night every day is found suitable for the production of wind power at the site and listed in the Table 2 as field data. There are few households surrounding this area so single micro-BTS with Omni directional antenna (O2) can handle the traffic generated by the local subscribers as well as tourists during the peak seasons. The estimated load pattern of second generation micro BTS at this location is listed in Table 1 and load pattern of mobile subscriber for twelve months is presented in Figure 3.

Number of solar panels is estimated based on standard test conditions (STC) with the I-V curved at 25°C. Though, there are other standards that offer better real-world approximations, STC has been considered as an optimum universal standard. The technical specifications of BP 485J model are used for estimation purpose only. Hence, if other solar models are used, similar capacity or higher is recommended to match the limited space of installation site. As wind power is available around 13 hours a day and solar power is available only for 5.42 hours per day in an average. So, the proposed hybrid model is designed for best fit power sharing from solar and wind and the portable generator. The theoretical solar and wind power and the actual power generation are also compared. The size of the battery charger is determined to cater the charging current from solar and wind turbine. The sizing of the battery is determined for the 48 hours of autonomy because of unavailability of sunshine during winter and rainy seasons and unavailability of wind during snowfall in winter. This can make up for two days power back up to the micro-BTS. In case of emergency, portable kerosene generator can be used. During the estimation, unreliable local electrical power has not been considered.

V. Result and Analysis

Estimation of solar, wind power systems with accessories are based on the load of the mobile base station considering wind speed, solar irradiance and BTS load as variables. An optimum solution is proposed here which is capable of meeting the load demand at peak hour. The peak load of the micro-BTS with microwave and VSAT transmission backhaul is considered as 750 W. The system is operated at -48 V DC. The average peak load per day is 18.0 kWh. The annual average sunshine insolation hour per day is 5.42 hours. Hence, minimum required power per day to operate the system is 3.32KW (18.0kWh/5.42 h). To allow for the normal energy losses and inefficiencies in a solar electric system, the excess 30% is to be added on the required sizing. The required size of the solar system is approximated as 5 kW. From the I-V curve of BP 485J, the maximum current produced by single module is 4.8A at 80W maximum power output. This is 12 V DC so we need 4 panels in a series to produce 48 V DC. The number of solar panels is 62.5 (5000/80) but they must be in 4 multiple to generate 48 V DC so we need 64 panels with 64/4 i.e. 8 number of arrays to feed 750W load of micro-BTS. From Solar Calculator (Korsun and Stranix, 1984) solar irradiance model, the average irradiance production at 28.805°N is found as 287.5 W/m^2 with 28 degree surface slope.

For 750W peak load base station, 1.65m radius wind turbine is recommended as shown in Table 3. However, the availability of the turbine in the market will be the final choice for the implementation.

Table 3: Rotor Size Estimation

	Efficiency	0.90
	Cp	0.59
	ρ	1.118
	Load Power	750
Month	Average Wind Speed	Radius of Rotor in m
Jan	6.45	0.87
Feb	6.90	0.78
Mar	7.20	0.73
April	7.05	0.76
May	6.15	0.93
Jun	5.10	1.23
Jul	4.20	1.65
Aug	4.20	1.65
Sep	4.20	1.65
Oct	5.40	1.13
Nov	6.30	0.89
Dec	6.15	0.93

The wind power produced in kW verses wind speed is plotted in the Figure 4 using 7.5 kW BWC-EXCEL-R/48. The average wind power generation is 1.7 kW which produces 35.41 A at 48 V DC. The maximum power generated by wind turbine is 3.13 kW and minimum is 0.78 kW so the battery charger should be carefully designed so that it can charge the battery during the peak power production from the wind turbine. This shows that wind turbine rating is much higher compared to the average electrical load. Here the rated capacity of 7.5 kW/ 48 V DC is proposed due to the availability of the product in the market. It is recommended to use 3.5 kW if available in the market. The life time of the turbine could be considered as 20 years and cost of this turbine in the market is about $15,500 excluding replacement and maintenance cost per year.

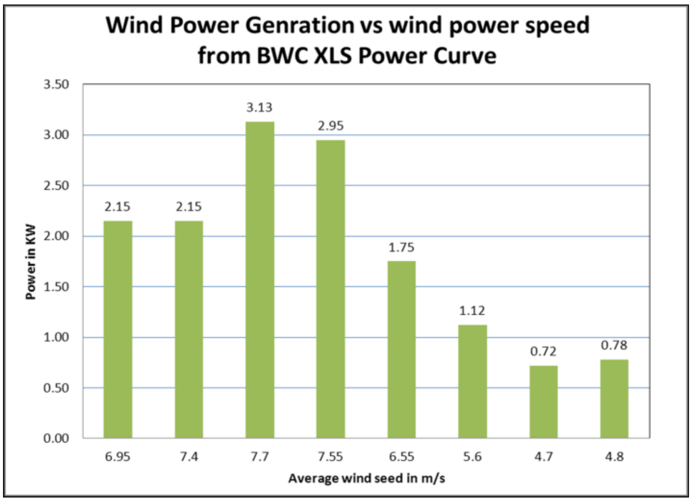

Figure 4: Wind Power Generation from BWC XLS Power Curve

Battery capacity is estimated based on the 18KWh load capacity of BTS per day, 48 hours of autonomy, 80% depth of discharge (DOD) and 25°C ambient temperature at battery bank. It is good not to discharge a deep cycle battery below 50% of its capacity. Gel type maintenance free batteries with DOD of 80% are good for such remote and diverse climatic condition site. Calculation is carried out without considering temperature effect on the batteries. The required capacity of battery with 80% DOD is 1000AH. For reliability, two battery banks with 500 AH each is proposed.

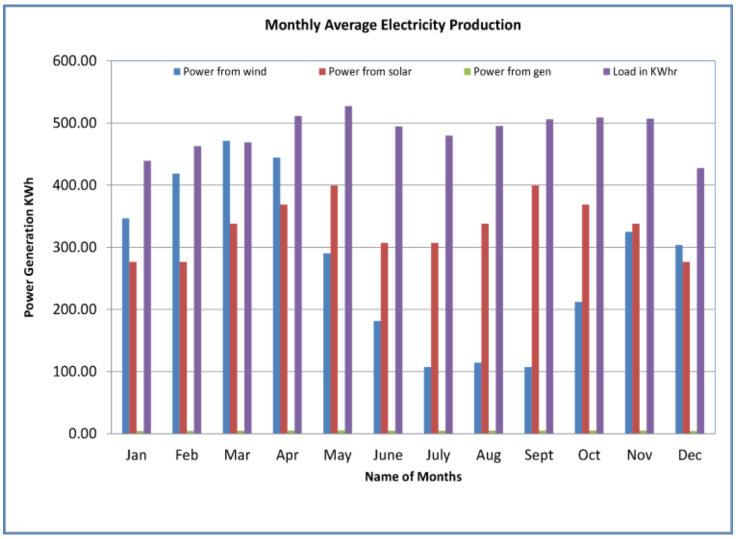

Figure 5: Load and Power Production from different sources of Hybrid System

Since, half of the total load is taken care by the wind generator so 50% of the solar capacity (32 panels of 80W each) is suggested to purchase and install at the site. Hence, battery charger cum regulator should be capable of handling of 20 A capacities (4.8A from each array x 4 number of arrays/0.8 efficiency). Similarly, the wind charger should be capable of handling the maximum current produced of 50A (1.80kW/48VDC with 25% safety margin). For the redundancy, two units of battery charger of 1+1 system, one having 20A capacity to connect the solar arrays and another of 50A to connect wind turbine output is required.

Figure 5 shows the power generation from each units and required load power for each month of a year which shows the generated power meets the load requirement. In case of the worst weather condition, portable generator should be operated to charge the battery. One KVA (Kilo Volt Ampere) generators with 25A rectifier is proposed to charge the battery once in two weeks during the rainy and winter season or wherever necessary to boost the battery.

Table 4: Cost Estimation of Hybrid Power System

S/N	Item with capacity	Quantity	Unit Price CA$	Total Price CA$	Tax 13%VAT+5% Custom	Grand Total in CA$
1	Wind Turbind with 7.5KW with tower, regulator/charger	1	$15,500.00	$15,500.00	$2,790.00	$18,290.00
2	Solar Panel of 80W	32	$640.00	$20,480.00	$3,686.40	$24,166.40
3	Solar Charge Regulator 20A	2	$185.00	$370.00	$66.60	$436.60
4	Solar Structure for 4 panel each	8	$105.00	$840.00	$151.20	$991.20
5	Battery of 1000AH in two banks with 500AH containing 2V 500AH each	48	$306.00	$14,688.00	$2,643.84	$17,331.84
6	Cable and assocesires	1	$2,000.00	$2,000.00	$360.00	$2,360.00
7	Portable Shelter 10'x12'	1	$9,000.00	$9,000.00	$1,620.00	$10,620.00
8	Portable Generator	1	$1,200.00	$1,200.00	$216.00	$1,416.00
9	Transportation, Installation and other	1	$5,000.00	$5,000.00	$900.00	$5,900.00
	Grand Total					$81,512.04

Price estimation is based on the data available from the present online market survey as shown in Table 4. The cost covers one set of 7.5kW turbine, 20m self-supported tower, portable shelter, 32 solar panels of 80W with structure, 1000AH with 2x24 units of 2V with 500AH each batteries, battery charge cum regulator and 1kVA generator cost. The installation site is far from the access road site so costs of porters are included. The cost for installation, civil, foundation, local porters, packaging, cables and accessories are stated based on the present local Nepalese market. Hence the total cost required to install the hybrid system at Mustang is about Canadian dollar $81,512.04 per BTS site.

VI. Conclusions

There is a challenge to provide reliable cellular mobile service at extremely remote locations where a reliable power supply is not available. The main causes of disruption of cellular mobile services are failure of transmission backhaul links and power supply. For the reliability of transmission backhaul links, VSAT and terrestrial microwave link are considered for the site and the hybrid power system is designed to meet the reliability. The proposed power solution consists of 7.5 kW wind turbine with 50 A battery charger and 2.5kW solar panel with 20A battery charger to charge 1000AH batteries can support the power requirement of a mobile BTS at a location of Mustang to serve maximum of 350 cellular mobile subscribers without any interruption of the mobile services. 1 kVA portable generator with 25A rectifier is proposed for a backup to charge the batteries whenever required. The cost of the hybrid system including portable generator, installation and transportation for the particular site of Mustang, Nepal is found approximately as Canadian dollar $81,512.04. This price may vary depending upon the location of the installation site and government taxes and duties. The proposed system ensures the reliability of power supply to run the 24/7 cellular mobile services at an extremely remote site of Nepal.

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