Hybrid power systems For Cell Sites In Mobile Cellular Networks

N. Faruk, *Member, IEEE,* A. A. Ayeni, *Member, IEEE,* M. Y. Muhammad, A. Abdulkarim, O. Moses

***Abstract*— the power consumption of wireless access networks has become a major economic and environmental issue. Providing dedicated low cost power supply to off-grid cell sites located in the rural and sub-urban areas of developing countries are most challenging, as most of the rural areas are not connected to the electricity grid and, even though they are connected, the availability of the supply is very limited to provide uninterrupted power supply. This paper proposes hybrid power systems (HPS) as alternative solution to the problems encountered with the off-grid cell sites. The paper further investigates the reliability figures and failure rate of the proposed hybrid power solution as compared with the conventional power system. The configuration of the HPS examined in this paper included a Solar Power System, Diesel generator and battery bank. Analysis of results shows that, after fifteen (15) years of operation, the reliability figures of both solar and hybrid power system are much higher than 80%. But that of the generator is already approaching 15%. Comparing these figures with the general bath tub, it can be seen that the reliability of generator after five years (i.e. 43800 hrs) of operation is already normal operation period and thereafter, the figure would degrade below 60% which would not be considered satisfactory operation. It was also found that, the proposed HPS system has very high reliability figures with a slight gain over the solar system and analysis of the mean time before failure (MBTF) shows that the, hybrid power system will work satisfactorily for twenty three (23) years before complete failure as compared with eight (8) years for generator system.**

***Index Terms*— Access network, hybrid system, Power consumption, , mean time before failure, reliability**

I. Introduction

THIE The physical limitations of the wired line communication systems in satisfying the ever increasing demands seem to be in favor of wireless systems. The consequent phenomenal growth in demand has led to a world-wide number of mobile subscribers to be 6 billion as at July 2010 [1] and the demand of the wireless technologies and services increases rapidly every year. Wireless communication system is one of the most important technologies for contributing to social and economic development around the world. Studies have pointed to the significant contribution of mobile communications to GDP growth as a key to sustainability. Mobile Communication is one of the most important technologies that contribute to social and economic development around the world. In Nigeria, the penetration of mobile communication in the market has created job opportunities which contribute to the economic development [2]. At microeconomic level, the sector contribution to GDP increased by 53% in 2003 making it the third highest contributor ahead of the financial sector which has been in operation for about 100 years. In respect of employment, over 135, 000 persons have been directly or indirectly employed by the operators [2]. In a Sunday Newspaper of 17 July, 2011 a new report by the GSM Association (GSMA) disclosed that Nigeria stands to gain an additional N862 billion by 2015 from mobile broadband. The last decade has seen exponential growth in wireless communication. As mobile communication network expansion is becoming extensively high, there is a need to provide an alternative energy sources.

Energy is one of the top expensive items for mobile network operators. In particular, base stations cause more than 80% of the operator's power consumption, which makes the design of base station a key element for determining both the environmental impact of wireless networking and the operational expenditure [3]. Utilizing renewable energy sources such as the solar, wind and bio – fuels as an alternative energy would be the ultimate solution to the mobile telecommunication industry.

In 2008, the GSM Association (GSMA) gathered nearly 800 worldwide mobile operators to launch a plan for deploying renewable energy sources for 118,000 new and existing base stations in developing countries by 2012 to save 2.5billion liters of diesel and cut CO2 emission up to 6.3 million tons per year [3]. In Nigeria, Airtel Nigeria (Mobile Operator) has embarked on upgrading 250 diesel powered stations to -sites, the company regretted that non-availability of regular grid power supply to sites across the country is responsible for over 70% of down time, resulting in poor QoS (Quality of Service) [4]. Hybrid power system is therefore proposed to solve the aforesaid problems.

This paper proposes hybrid power system s as alternative solution to the problems encountered with the off-grid cell sites in mobile communication networks. The paper further investigates the reliability figures and failure rate of the proposed hybrid solution as compared to the conventional power system. The paper is organized as follows; Section 2 introduces off-grid sites, Section 3 gives the power consumption of realistic macro cells in Nigeria. Comparative

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reliability analysis is presented in Section 5 and finally, Section 6 concludes the paper.

II OFF-GRID CELL SITES

An off-grid cell site is a cell site that is not connected to the power grid. Usually the site is off the grid because it is situated in a place which is difficult to get to or it is not connected to the main power grid. In Nigeria, off-grid sites could be found mostly in the rural areas.

Apparently, future network expansions are focusing on these areas (Rural areas). For instance, IT news Africa of Tuesday, 2 of August, 2011, the South Africa's second largest mobile operator, MTN plans to roll out over 1 000 Universal Mobile Telecommunications Systems (UMTS) base stations in rural areas over the next two years. Tagged, "*Rural mobile broadband project*". Providing dedicated low cost power supply for these sites could be challenging as most of the rural areas are not connected to the electricity grid and, even when they are connected, the availability of supply is very limited to provide uninterrupted power to satisfy minimum required QoS. A common solution involves fuel cells connected to a generator; but this has prohibitively high costs and high negative environmental impacts. A new possibility is brought by renewable sources, mainly solar power and wind power. In Nigeria, towards the North East of the country, temperature can rise up to 40^0C during high solar activity. In Maiduguri, Nigeria, the average monthly temperature over the year in 2009 was found to be 34.75^0C. This value was calculated from the data obtained from [5]. In places like Sokoto, Nigeria, the warmest months are February to April, where daytime temperatures can exceed 45 °C (113.0 °F). Highest recorded temperature is 47.2 °C (117.0 °F), which is also the highest recorded temperature, in Nigeria. Similarly, the average sunlight hour per day within these months (i.e. February, March and April) was 6.7, 6.4 and 6.2 respectively [5]. Also in November and December, the average sunlight hours per day are 6.6. All these areas could utilize PV solar cells as an alternative solution. The PV solar cells or wind power could be backed up by a fuel generator system for redundancy which allows the cell site to work when the renewable sources are not enough.

III REALISTIC POWER CONSUMPTION OF MACRO BTS SITES IN NIGERIA

There are several factors that could affect the BTS power consumption; these include the traffic load which varies as a function of time due to varying nature of demand for services and the demography of an area. Other factors could affects the power consumption of individual components which would subsequently alter the overall power consumption. The most power consuming components are the power amplifier and the air conditioning systems. These indicate that, the power consumption of individual BTS may vary with location area. Considering realistic power consumption for a typical mobile operator in Nigeria BTS, this includes both the transceivers and the microwave radio unit for 2G network some sites are used for backbone only. In the event of network upgrade, 3G network is usually installed in the same BTS to minimize cost. This is shown in **Table 1**, the power consumption for the site with 6 PDH (Plesiochronous Digital Hierarchy) and 2 SDH (Synchronous Digital Hierarchy) is 5868W and this decrease to 4478W for 1 PDH and site. Generally, the power consumption increase with increase in either microwave units or the number of transceivers.

TABLE 1- REALISTIC POWER CONSUMPTION OF BTS IN NIGERIA

Configuration/Equipments	Power (Watts)
6 PDH RADIOS, 2 SDH RADIOS, (6TRX 900BAND, 12TRX 1800BAND)	5868
1PDH RADIO, (2G 6TRX BAND, 12TRX 1800BAND)	4478
5 PDH RADIO, 5 SDH RADIO, MUX, (6TRX 900BAND, 22TRX 1800BAND), 3G	8460
1PDH RADIO, 2 SDH RADIO, (8TRX 900BAND)	6108
2G 9TRX 900BAND, 36TRX 1800BAND	7240
2G 6TRX 900BAND 36TRX 1800BAND + 3G	8580

IV HYBRID POWER SYSTEM S

Hybrid power systems are designed for the generation of electrical power. They are generally independent of large centralized power grids and could be used in remote areas. Hybrid systems may contain a number of power generation devices such as wind turbines, photovoltaic, micro-hydro and/or fossil fuel generators. Hybrid power system s are seen as a way to provide power to the many remote areas in the developing world where the costs for large scale expansion of electrical grids is prohibitive and the transportation costs of diesel fuel are also very high [6]. The use of renewable energy sources for hybrid power generation systems would reduce the use of expensive fuels, allows for the cleaner generation of electrical power.

Telecommunication systems require safe, long life and uninterruptible power supply in order to provide uninterrupted service [7]. Standalone homogenous renewable power systems cannot meet the power requirements of telecommunication systems. For example, Standalone solar systems are not capable of providing uninterrupted power because of the variation of luminosity within a 24 hour period and large area of land required to installed PV cell which is not feasible in urban areas even if it is feasible in rural and sub urban areas. Furthermore, in cases where cell sites are dispersedly located and will be difficult to collocate only off grid renewable energy technologies will be appropriate for telecommunications systems deployment. Evidently, based on current technologies, the deployment renewable energies for telecommunication purposes (especially for cell sites) will require complementarily combining several sources of renewable energy source, conventional generators (Diesel generator, LPG turbines e.t.c) and energy storage systems[1] (battery bank) which is selected based on their comparative advantage while maintaining uninterrupted supply and

[1] Recent developments in energy storage technologies have proven the future possibility of having energy storage systems which are more efficient than battery banks.

acceptable power quality, hence the Hybrid power system (HPS) [8][9].

There are different configurations – combinations of renewable and convectional energy sources – being deployed for telecommunication purposes: Diesel-Battery; Solar-Diesel-Battery; Diesel-Battery-Wind; Solar-Diesel-Battery-Wind; Solar-Battery [10]. According to [11], the configuration of a HPS depends on three factors: Resource (renewable source), Load, and Cost (CAPEX and OPEX). Thus, the HPS is selected such as to optimize the available resources vis-à-vis various constraints to improve performance, economy and reliability. The control system, center of optimization, does operation overview, planning & scheduling, co-ordination and execution, and load management [9]. In hybrid power system shown in **Figure 1**, two or more sources of power could be used to provide the required power to the load. In **Table 1**, the configuration 2G 6TRX 900BAND 36TRX 1800BAND + 3G, requires 8580W of power this is quite enormous for a single power source. Therefore, two sources such as solar and generator could be used as shown in **Figure 1.**

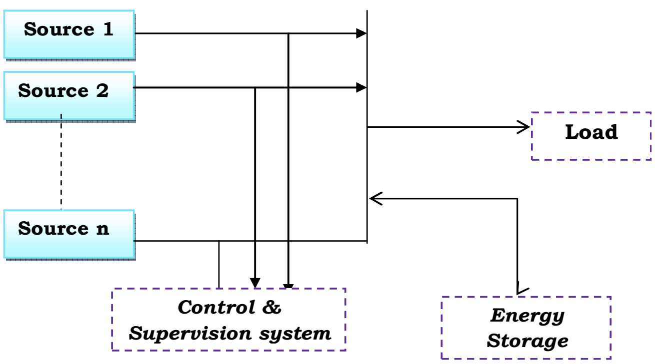

Fig.1. Schematic Diagram of a basic HPS

Figure 1 above, shows the schematic diagram of a basic power hybrid system. Multiple sources would be used to provide the required power supply to the load. A control and supervision system is used to supply of power and switching if other sources are used for redundancy. The grid characteristics (frequency and voltage) and power quality parameters of the busbar could also help reduce the complexity and efficiency busbar of an HPS. Having an homogenous busbar (for instance DC busbar , Frequency =0) could reduce the complexity of the HPS, which can be achieved by having DC loads only. This scenario can be achieved by deploying outdoor BTS which does not require air conditioning systems. Rosenthal *et al,* opined that HPS provide a realistic alternative for conventional energy sources in terms of economy (fuel consumption and maintenance) and environmentally benign although the CAPEX of such systems is high. However, the life-cycle cost is comparatively less, considering the cost of emissions.

Different mode of operation for the HPS is possible. In **Figure 1**, source 2 could be used simultaneously with source 1 to provide the required 8580W power or, either of the two could be used as redundancy incase of failure. Another possible mode of operation is that, sources 1and 2 would each have the capacity of 8580W but the supply would be alternative in such a way that, source 1 will provide power for the first 12 hrs and source 2 will provide for the remaining 12 hrs. This configuration could prove effective and may in turn cut the carbon emission by 50% when solar and generator systems are deployed. And it could also extend the life-time of each system.

The investigations and findings of this paper is based on PV Solar –Diesel Generator- and- Battery Bank – Hybrid power system configuration

V COMPARATIVE RELIABILITY AND MEAN TIME BETWEEEN FAILURE RATE ANALYSIS

A. RELIABILITY ANALYSIS

In general, reliability designates the ability of a system to perform its assigned function, where past experience helps to form advance estimates of future performance. Reliability is measuring index for the performance of engineering systems. [12], defined reliability as the probability that a device or system will perform its prescribed function adequately for the period of time intended under specified operating conditions. Reliability can be determined through the mathematical concept of probability by identifying the probability of successful performance with the degree of reliability. If a device or system does not fail during the time of service it is said to perform satisfactorily. On the other hand, some devices are expected to fail, be repaired and then returned to service during their entire useful life. In this situation a more appropriate measure of reliability is called availability of the device in question. Therefore, in this work the reliability of the design is evaluated using exponential distribution model. The exponential distribution model is defined in [13], this is given in equation (2). The exponential failure density function $f(t)$ is defined by:

$$f(t) = \lambda e^{-\lambda t} \qquad t \geq 0 \,\&\, t > 0 \qquad (1)$$

Where, λ is the constant failure rate, and t is operating time.

The reliability function is $R(t)$ given by;

$$R(t) = e^{-\lambda t} \qquad (2)$$

The generic failure rate, λ_G of each component that makes up the solar power system is obtained from the Military Hand-book (**MIL-HBK-217 Notice 2),** using parts count method of reliability prediction. In this paper, it is assumed that the failure of any components that make up solar power system will result to system failure. Therefore, based on series theorem of reliability, the total failure rate of the system is 1.6342×10^{-6} failures per hour, similarly the failure rate of the diesel generator less than 1500 KW is 0.14098×10^{-6} failures per hour. In predicting the reliability of the hybrid power system , it is assumed that the two power sources solar and generator works simultaneously as such there exists partial redundancy and therefore, the failure of one system would affect the overall reliability of the system but will not cause the overall system failure. Therefore, the failure rate of the hybrid power system is obtained by using series theorem of the reliability algebra. Using Microsoft Excel and Microsoft origin application packages; the reliability of the conventional diesel generator, solar power and hybrid power system was evaluated for the period of 30 years, the results is shown in **Figure2.**

In **Figure 2,** all the systems followed normal exponential distribution reliability curve, with generator system decaying sharply close to zero figure after 28 years (i.e. 250000 hrs). It can be seen that the proposed system has very high reliability figures with a slight gain over the solar system. This means that, both the solar and the hybrid power system would perform their function satisfactory for over the prescribed period; the proposed hybrid power system would be reliable for at least twenty years satisfactorily. This is not possible with the present system that relied on the generator as the major source of energy to the cell sites.

After fifteen (15) years of operation, the reliability figures of both solar generator and hybrid power system are much higher than 80%. But that of the generator is already approaching 15%. Comparing these figures with the general bath tub, it can be seen that the reliability of generator after five years (i.e. 43800 hrs) of operation is already normal operation period and thereafter, the figure would degrade below 60% which would not be considered satisfactory operation. But the reliability of both solar and hybrid power system would approaches wear out period after almost twenty five (25) years of operation.

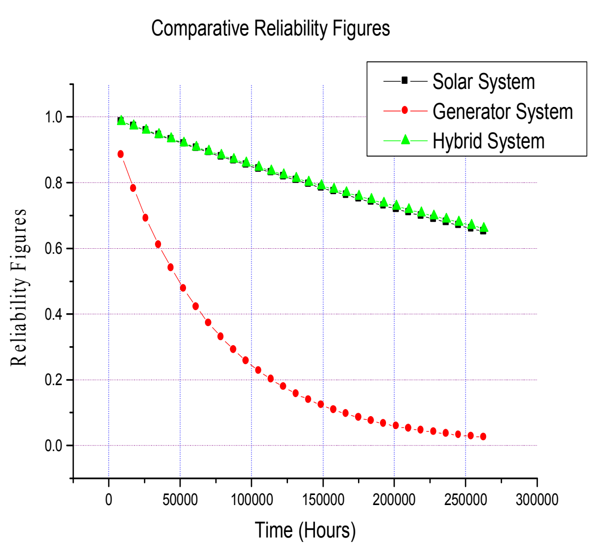

Fig. 2: Hybrid power system Reliability Figures

When observed critically, it was noticed that, there was almost overlap of reliability figure for solar and hybrid over the period of 17 years (150000 hrs) of operation, thereafter, the hybrid power system shows slight higher index over the solar. This means that, higher reliability figures are clear indication of the suitability of the proposed hybrid system.

TABLE 2- RELIABILITY FIGURES OF DIESEL, SOLAR AND HYBRID POWER SYSTEM FOR 10 YEARS OPERATION

Time (hrs)	Diesel Generator system (DGS)	Solar Power System (SPS)	Hybrid Power System (HPS)	Reliability Gain of SPS Over DGS (%)	Reliability Gain of HPS Over DGS (%)
8760	0.88382	0.98579	0.98627	10.34398807	10.3876221
17520	0.78114	0.97177	0.97274	19.61678175	19.6969385
26280	0.69039	0.95796	0.95939	27.93122886	28.0386496
35040	0.61018	0.94434	0.94622	35.38556029	35.5139397
43800	0.53929	0.93092	0.93323	42.06913591	42.2125307
52560	0.47664	0.91769	0.92042	48.06089202	48.2149454
61320	0.42126	0.90464	0.90779	53.43340998	53.5949944
70080	0.37232	0.89179	0.89533	58.25026071	58.4153329
78840	0.32906	0.87911	0.88304	62.56896179	62.7355499
87600	0.29083	0.86661	0.87092	66.44049803	66.606577

In **Table 2**, the reliability figures of diesel, solar and hybrid system for 10 years of operation, the difference in reliability figures can be seen from 0.98579 for solar power system (SPS) to 0.98627 for hybrid power system (HPS) representing about 0.4% increase. One of the differences between the solar system acting alone and the hybrid power system is that, there would be increase in the initial cost of the proposed system but the running cost may drop. The costs of the hybrid power system will be higher compared to solar or generator alone, even though the system indicated a slight increase in the reliability figures.

B. MEAN TIME BETWEEN FAILURES (MTBF):

[13], defined Mean Time between failures as the length of time a system will run without failure is of importance to the system users. MTBF can be obtained by stressing a large number of components under known conditions for a period of time noting the number of failures. The mean time to failure of the hybrid, solar power system and generator are obtained using the equation 3. That is;

$$MTBF = \frac{1}{\lambda} \qquad (3)$$

Substituting the total failure rates of the PV solar power system and generator into equation (2), the MTBF of the proposed hybrid power system is about twenty three (23) years compared to the MTBF of the generator that has less than ten years. Similarly, the MTBF of the hybrid power system is between the PV solar system and generator, this is due to an increased in the failure rate incurred from generator system; and from equation (3), there would be corresponding decrease in the mean time between failures of the system. Based on this, it can be seen from **Figure 3** the solar system, hybrid and generator system will work satisfactorily for seventy (70) and twenty three (23) eight (8) years respectively in that order before complete failure. Therefore, the paper is proposing either PV solar power or hybrid power system as one of the best alternative powering cell sites of the base station.

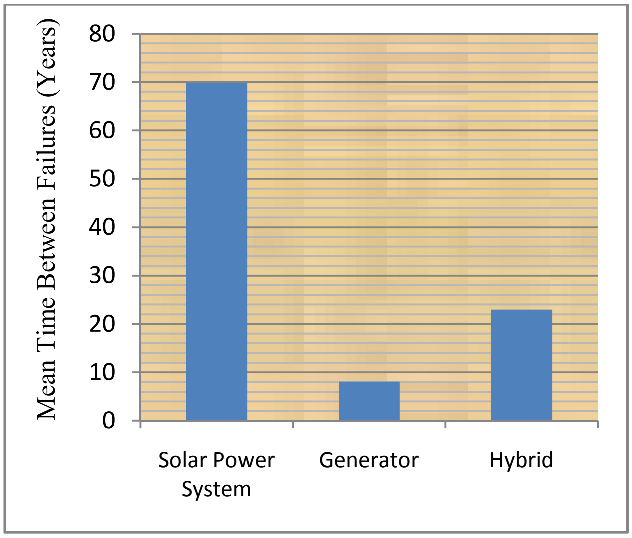

Fig. 3. Comparative mean time between failures

VI CONCLUSIONS

In this paper, we have proposed hybrid power system as alternative to power off-grid cell sites in mobile communication. We also investigate the reliability and mean time between failure (MTBF) of the proposed hybrid solution as compared with the conventional power system. Analysis of results shows that, both the PV solar and the hybrid power system would perform their function satisfactory for over the prescribed period; the proposed hybrid power system would be reliable for at least twenty years satisfactorily while approaching wear out period after almost twenty five (25) years of operation.

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