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Analysis of Solar Powered Micro-Inverter Grid Connected System for a Cellular Communication Network

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Abstract- The power consumption of wireless access networks has become a major economic and environmental issue. Providing dedicated low cost power supply to cell sites located in the rural and sub-urban areas of developing countries is 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 developed a Solar Powered Micro-Inverter Grid connected System as an alternative solution to the problems encountered with power supply in cell sites. The configuration of the Solar Powered Micro-Inverter Grid connected System examined in this paper include a Solar Power System, Diesel generator, battery bank and Grid. Analysis of results shows that, after fifteen (15) years of operation, the reliability figures of solar power system is much higher than 80%. But that of the generator is approaching 15%. Comparing these figures with the general bath tub, it can be seen that the reliability of generator after five years of operation degrades by 60%. It was also found that, the developed Solar Powered Micro-Inverter Grid connected System has very high reliability figures with the Mean Time Before Failure (MBTF) of about twenty three (25) years before complete failure as compared to eight (8) years for generator system.

***Keywords*:** Base Transceivers Station (BTS), energy conservation, power consumption, Solar, Renewable energy, Micro-Inverter, Switch Mode Power Supply (SMPS).

I. INTRODUCTION

The limitation of wired communication system in meeting the ever increasing demand of subscribers is in favor of wireless systems. The growth in demand has led to an increased number of subscribers worldwide to about six (6) billion in 2011. [1]. In Nigeria the penetration of mobile communication has created job opportunities which contribute to her economic development. In 2003 the sector contributed 53% of GDP increment with employment of over 135,000 people. The last decade has seen exponential growth in wireless communication. Energy is the most expensive item for mobile communication operators. Base Transceiver station (BTS) consumes more than 80% of the operator's power consumption, which makes the design for base station a key element for determining both the environmental impact and operational expenditure for a wireless network. Using renewable energy sources such as Solar, Wind, Bio-fuel, etc. as alternative sources of energy will go a great length in solving the energy problem in the mobile communication industry. In 2008, the GSM Association (GSMA), gathered nearly 800 worldwide 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 litres of diesel and cut CO_2 emission by 6.3million tons per year. [2]. In Nigeria, Airtel Nigeria regretted that non availability of regular grid power to sites across the country is responsible for over 70% of downtime, resulting in poor quality of service (QoS). Solar Powered Micro-Inverter Grid connected Systems are therefore developed to solve the afore-mentioned problems. This paper developed a Solar Powered Micro-Inverter Grid connected System as an alternative solution to the economic problems encountered in cell site power supply, running on generators or grid or both.

Fig 1: Photovoltaic cells (PV) at BTS Site [3].

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 in demand of the services and the statistical population of an area. Other factors affect 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. Sample of realistic values from some BTS site are shown in Table 3.

Table 1: Realistic Power Consumption of BTS in Nigeria [3].

CONFIGURATION/EQUIPMENT'S	POWER(Watts)
6 PDH Radios, 2 SDH Radios, (6TRX 900BAND, 12TRX 1800BAND)	5868
1 PDH Radio, (2G 6TRX 900BAND, 12TRX 1800BAND)	4478
5 PDH Radios, 5 SDH Radios, MUX, (6TRX 900BAND, 22TRX 1800BAND), 3G	8460
1 PDH Radio, 2 SDH Radios, (8TRX 900BAND)	6108
2G, 9TRX 900BAND, 36TRX 1800BAND	7240
2G, 6TRX 900BAND, 36TRX 1800BAND	8580

These indicate that, the power consumption of individual BTS may vary with location area. Considering realistic power consumption for typical mobile operator in Nigeria, these include the transceivers and the microwave radio units 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 3.

Solar As Alternative Renewable Energy to Power Cell Sites

Solar power is more expensive to install, but for low and medium capacity sites like the microcell stations, it can prove a cheaper option than diesel generator system. In Nigeria where most of the site stations are not directly connected to the electricity grid and if the grid fails as in most of the time, these sites are powered by diesel generators especially in remote (rural) areas; therefore, the solar power system should be a better option. Solar–powered sites have a technical life time of 20–30years [4] and they could prove much more reliable than diesel generator system which needs regular maintenance and re–fuelling. Reliability and availability are also important issues to be considered when chosen an alternative energy source. In terms of the environmental impact, the alternative source (Solar) produces no noise, CO2 emission or smell, thereby reducing environmental pollution. Using solar system as an alternative energy source will greatly reduce Total Cost of Ownership (TCO) which is the annual amount the network operator spends in order to maintain and sustain the level of performance of the network based on coverage area and capacity expansion (4). These includes costs such as operation and maintenance, site rental, power, spares, training and support, transportation and site visits. However, this would help to make communication more affordable to individuals and the society at large. On the other hand, one of the challenges facing solar energy system is that the highest efficiency of the system depends on full sunlight exposure and therefore it effectiveness varies from time to time and in particular, from location to location.

Micro-Inverter

A solar Micro-Inverter, or simply Micro-Inverter, is a device used in Photovoltaic system that converts direct current (DC) generated by a single solar module to alternating current (AC). The output from several micro-inverters is combined and often fed to the electrical grid. Micro-inverters contrast with conventional string and central solar inverters, which are connected to multiple solar modules or panels of the PV system.

Advantages of Micro-Inverter

- The main advantage of micro-inverters is their ability to maintain a robust and consistent flow of power even with shade on one or more of the panels, as the string are in parallel rather than series as with a conventional inverter.
- Because the micro-inverters service an individual module, the power performance and the overall health of each module can be tracked and monitored in real time.
- Monitoring the array with conventional string inverters consist of checking the aggregate output of each string of modules for performance.
- With Micro-inverters, a bad module can be detected virtually instantaneously and the best part, identified remotely.
- String inverters respond to the least efficient module in a string.
- Variations in modules have no effect on the ultimate output of the array since modules with micro-inverters are independent contributors to the power output. Different types and different manufacturers' modules can be used in a "string" of Micro-inverters.
- When string is built for a conventional inverter, all the modules need to at least have the same electrical characteristics and preferably be made by the same manufacturer, which leads to Maximum Power Point Tracking (MPPT). The way Maximum Power Point Tracking works (basically) is to create a resistance or load which then "defines" the amperage that is flowing from the array or from a single module as in the case of a micro-inverter.
- In string inverters, the resistance is in response to the amperage output of the aggregate of modules in the array. Different modules in the string have different Maximum Power Point's which means some modules are not performing as well as they could, thereby resulting in loss of power.
- Since each micro-inverter contains a maximum power point tracker, each module performs to its maximum best.

PV Panels Using Micro-Inverter Technology

Solar panels produce direct current at a voltage that depends on module design and lighting conditions. Modern modules using 6-inch cells typically contain 60 cells and produce a nominal 30V. For conversion into AC, panels may be connected in series or parallel. When connected in parallel a micro-inverter is used but when in series it produces an array that is effectively a single large panel with a nominal rating of 300 to 600 VDC, the power then runs to a central or string inverter, which converts it into standard AC voltage, typically 230 VAC / 50 Hz or 240 VAC / 60 Hz

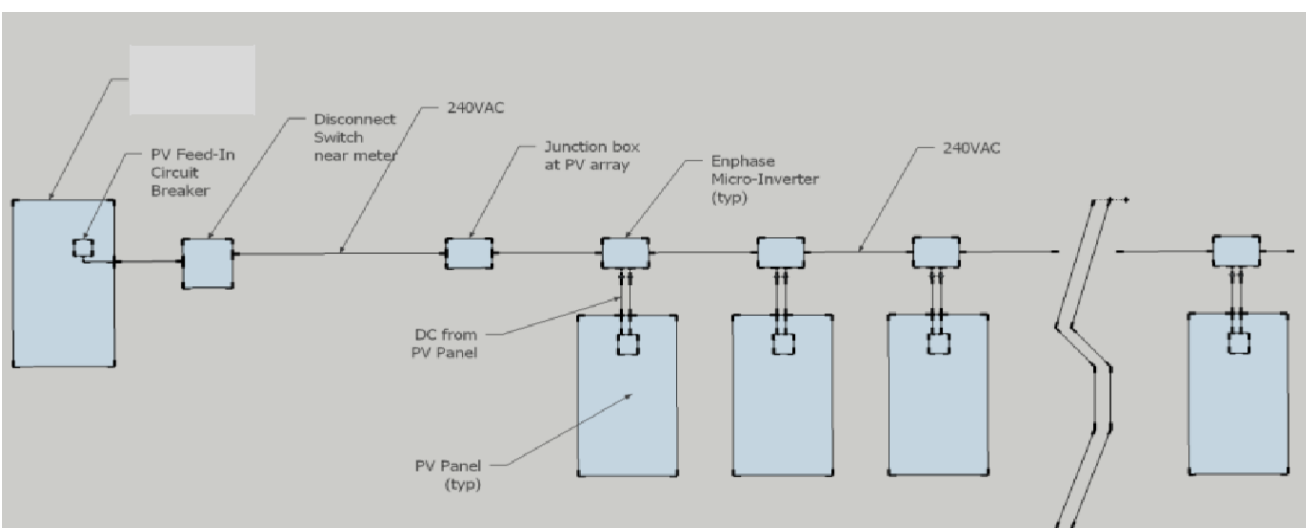

Fig 2: Block Diagram of Solar Powered Micro Inverter System. [5].

Micro-inverter concept

Micro inverters are small inverters rated to handle the output of a single panel. Modern grid-tie panels are normally rated between 225 and 275W, but rarely produce this in practice, so micro inverters are typically rated between 190 and 220W. [5]. Many design issues inherent to larger designs simply go away because it is operated at this lower power point and the need for a large transformer is generally eliminated. Large electrolytic capacitors can be replaced by more reliable thin-film capacitors and cooling loads are reduced so no fans are needed. Mean Time between Failure (MTBF) is quoted in hundreds of years.

Fig 3: A Micro-Inverter

More importantly, a micro inverter attached to a single panel allows it to isolate and tune the output of that panel. For example, in a 10-panel array with micro inverters, any panel that is under-performing has no effect on panels around it. In that case, the array as a whole produces as much as 5% more power than it would with a string inverter. When shadowing is factored in, if present, these gains can become considerable, with manufacturers generally claiming 5% better output at a minimum, and up to 25% better in some cases. Furthermore, a single model can be used with a wide variety of panels, new panels can be added to an array at any time, and need not have the same rating as existing panels. [5] Micro-inverters produce grid-matching power directly at the back of the panel. Arrays of panels are connected in parallel to each other, and then to the grid. This has the major advantage that a single failing panel or inverter cannot take the entire string offline. Combined with the lower power and heat loads, and improved MTBF, some suggest that overall array reliability of a micro inverter-based system is significantly greater than a string inverter-based one. This assertion is supported by longer warranties, typically 15 to 25 years, compared with 5 or 10 year warranties that are more typical for string inverters. Additionally, when faults occur, they are identifiable to a single point, as opposed to an entire string. This not only makes the fault isolation easier but unmasks minor problems that might not otherwise become visible – a single under-performing panel may not affect a long string's output enough to be noticed.

Micro inverters have become common where array sizes are small and maximizing performance from every panel is of great concern. In these cases, difference in price-per-watt is minimized due to the small number of panels and has little effect on overall system cost. The improvement in energy harvest given a fixed size array can offset this difference in cost. For this reason, micro-inverters have been most successful in the office and residential market, where limited space for panels constrains array size and shading from nearby trees or other objects is often an issue. Micro-inverter manufacturers list many installations, some as small as a single panel and the majority under 50. [5].

Designing with Micro-Inverters

- Micro-inverters have branch circuits' analogous to string inverters'. The difference being the modules are in parallel not series so the voltage exiting the micro-inverter remains constant at 240V or 208V depending on the type of system being fed and the amperage.
- The amperage exiting the micro-inverter is about 1A depending on the type of micro-inverter.
- To build a branch circuit of modules the installer needs to check the micro-inverter cut sheet to find out the maximum number of modules in a single branch circuit. In a 240V M215 the maximum is 17 modules. In a 208V M215 the maximum is 21 modules.
- The manufacturer recommends a 20A double pole breaker for interconnection regardless of 208V or 240V.
- The next question is, "is the module compatible with the micro-inverter?" On the Enphase website there is a compatibility list about 22 pages long with every conceivable module on it. Make sure the module and micro-inverter are compatible. The micro-inverter can be damaged if the module is not compatible with it.

- As explained earlier in the discussion, Modules come in 60 cell and 72 cell varieties. The M215 is for 60 cell modules. The M190 and M210 supports 60 cell as well as 72 cell, Sanyo, and Sun-Power modules.
- The maximum wattage module that the Enphase micro-inverters will tolerate is 280W.
- Just as a design tip, it is best to use the highest wattage module that the micro-inverter can take.

II. THE BTS OR BASE TRANSCEIVER STATION

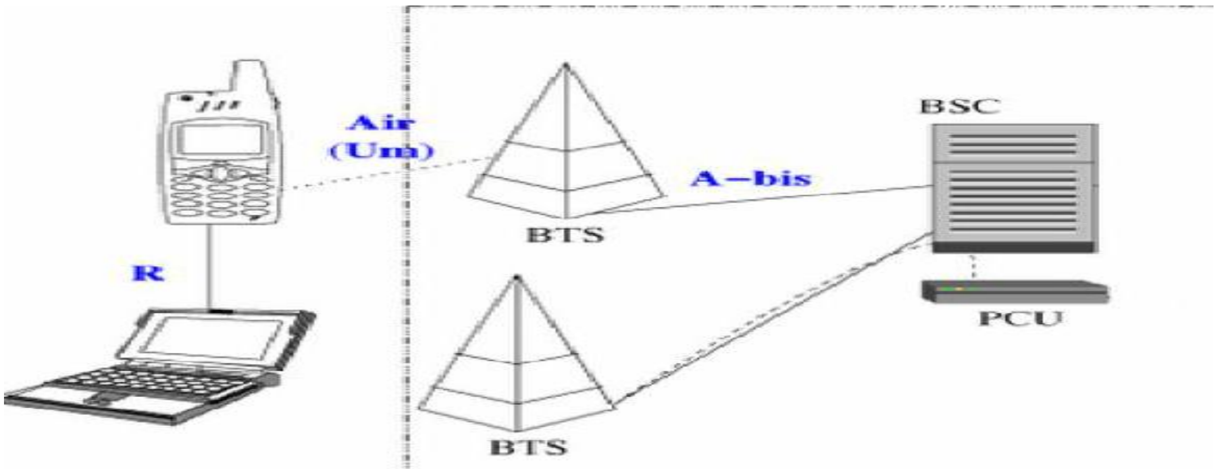

Fig 4: GSM BSS Network. [6].

The BTS contains the equipment for transmitting and receiving of radio signals (transceivers), antennas, and equipment for encrypting and decrypting communication with the Base Station Controller (BSC). The BTS with the BSC forms the Base Station Subsystem or BSS, whose function is to handle the traffic and signaling between a mobile phone and the Network Switching Subsystem.

The BTS site layout

As long as the BTS is the final fixed body that the GSM signal passes before it gets to the mobile phone, these sites should be spread in every locations the vendor wants to have subscribers for his network. The BTS sites may be located inside the City Centre, around the city or in remote areas. However, for the BTS site to work it needs a supply of electric power in a range of 10 to 30kW. This power is dependent on the area to be covered, the topography of the area and number of subscribers. The power supply of BTS site should be highly reliable and secure to keep the mobile phone of the subscribers working all the time.

Fig 5: BTS Site Layout. [6].


Fig 6: BTS Shelter for Indoor BTS

Power system configuration for cell towers

This work considered the power system configuration, types of loads and important generator set features for any cell tower application. Power requirements for a Base Transceiver Station (BTS) vary widely depending on a number of factors:

- Is the site indoor or outdoor?
- Is the location urban or rural?
- In which region is the site?

In light of these variables, it is unrealistic to create one load profile for all cell tower power system configurations. Table 1 summarizes regional variations for most generator set system requirements.

Table 2: Power System Requirements by Region. [7].

Region	**Duty**	**Load Profile**
Africa	Prime	7.5–40 kVA, 1- & 3-phase, depending mainly on the size and number of air conditioning loads
Asia Pacific	Prime	25–40 kVA, 3-phase
Latin America	Prime	5–30 kW, 1-phase
Middle East	Prime	25–40 kVA, 3-phase
North America	Standby	20–60 kW, 3-phase

Outdoor Radio Transceivers or BTS

Radio transceivers are being designed to handle high ambient temperatures, in order to eliminate air conditioning in the cell tower BTS shelter. The impact of this trend is substantial, because air conditioning increases the size of generators needed for steady state operation. For example, in a typical cell tower, the BTS load itself requires only about 2 to 3kW, but up to 12kW generator sets are being used to meet the occasional peak power requirements for starting air conditioning units. Therefore, as the use of the high ambient switching radio equipment increases, the size of the generator set required to power future telecom cell towers will be reduced substantially.

Power Schemes for BTS

In most regions, a standby power system configuration typically uses 3-phase AC output power, where the single-phase loads are balanced equally among the three phases. Most cell tower operators in North America and Europe use one diesel-fueled generator for emergency backup to the main utility power. But in developing countries and prime power markets, two generators are typically used: one running continuously and alternating with the other generator set weekly, or whatever interval the *Automatic Transfer Switch* (ATS) is set to use. The differences in the size of transceivers, ambient environmental conditions, type of rectifiers and inverters used in the *Switch Mode Power Supply* (SMPS), number and size of batteries, and other factors (such as maximum allowable fuel tank size limit or design for future load expansion) are the major variables that need to be considered when selecting the generator set and power system configuration for the cell tower. At the same time, there are certain loads that every base transceiver station (BTS) will use. These loads and power schemes applied are shown in Figure 8, which shows a typical one-line electrical layout for a base station employing a 12 kW (15 kVA) generator set that would meet the demands of a cell tower in most regions.

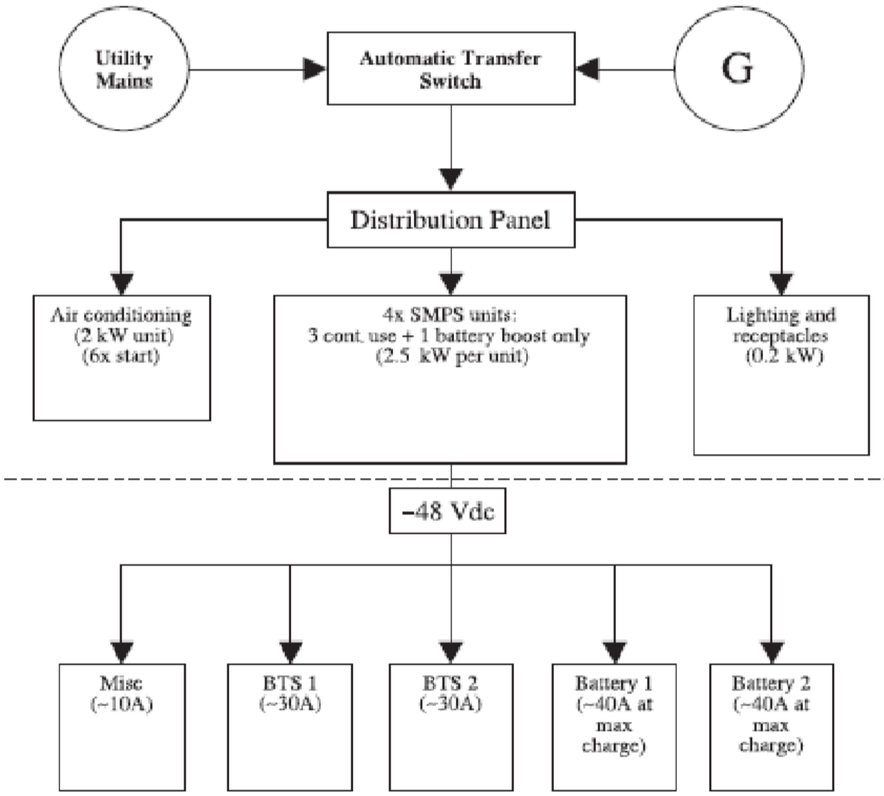

Fig 7: Typical Electrical Layout for Loads on a Telecom BTS. [6].

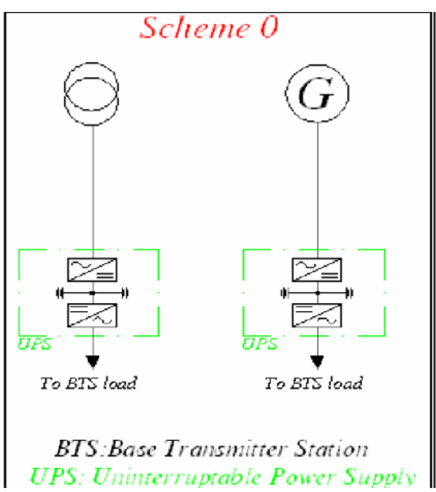

Fig 8: Scheme 0. [6].

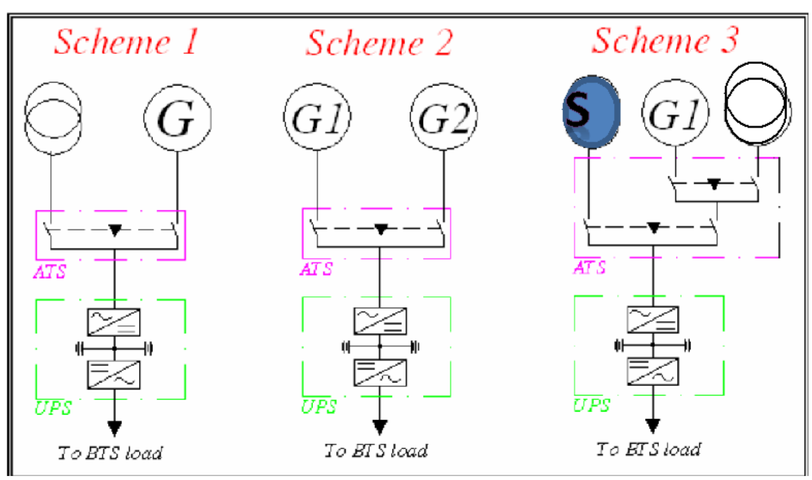

Fig 9: Power Schemes 1, 2 and 3. [6].

From figure 6, it can be seen that the load consists mainly of microwave radio equipment and other housekeeping loads such as lighting and air conditioning units. The actual BTS load used on the cell tower is powered via the SMPS, which is the direct current (DC) power plant. In some regions, such as India and East Asia, the witch Mode Power Supply (SMPS) is typically part of a more complex Power Interface Unit (PIU), which includes the transfer switch and a static line conditioner to maintain the critical operation power input between the utility and generator(s). The PIU also protects the equipment from input power supply surges due to lightning, monitors the health of the battery and controls the charging rate of the battery banks. The rectifiers and inverters in the SMPS and PIU systems have minimal power losses, and run at efficiencies as high as 95–98% with a power factor close to unity.

Power Schemes depicted in figures 8 – 10 above. Scheme 0: Uses Mains or emergency generating set

Scheme1: The supply is either from the Mains or the emergency generating set. This is the standard scheme that is applied in more than 90% of the applications.

Scheme 2: The supply is from either of two generating sets where each of them will work 6 to 12 hours periodically. This scheme is applied where no mains is available as in remote areas.

Scheme 3: The developed Solar Grid connected system supply is from the Solar Powered Micro-Inverter System, Mains and One emergency generating set.

Hence, the importance of the site, its location and the status of the mains supply should be studied carefully before selecting the best scheme for the BTS site. [6].

48V Supply for BTS Equipment

Although other voltages are possible, most radio transceiver loads used in telecom base stations run on a 48V DC bus. This system has the positive side of the battery connected to ground and is at zero potential otherwise referred to as the positive ground system or common or return wire. The negative side of the battery becomes the “Hot” conductor.

Advantages of Using Negative Voltage (Positive Zero Potential).

- Positive voltage causes comparatively more corrosion in metals.
- Negative voltage is safer for human body while doing telecom activities.
- Negative voltage neutralizes the effect of thunder in the equipment’s or circuits.
- Negative voltage is safer in transmitting power over long telephone lines.
- Negative voltage helps in reducing the leakage current to ground caused by moisture from electroplating away the copper in the wire. [7].

This practice originated in the early days of telephony, when 48V DC was found to be suitably high for long telephone lines but low enough to prevent serious injury from touching the telephone wires. Consequently, most electrical safety regulations consider DC voltage lower than 50V to be a safe low-voltage circuit. It is also practical, because this voltage is easily supplied from standard Valve Regulated Lead Acid (VRLA) batteries by connecting four 12V batteries (like those used in cars) in series, making it a simple system. The positive grounded or -48V system is another survivor from earlier industry practice.

III. SYSTEM MODELING

Theoretical Power Consumption of Base Transceiver Station (BTS)

Base Transceiver Station (BTS) is a transceiver that acts as interface between the mobile stations (MS) and the network. A BTS has between 1 and 16 Transceivers (TRX), depending on the geography and demand for mobile service in an area. There are several power consuming components inside the BTS. Some components are used per sector such as the digital signal processing (DSP) which is responsible for system processing and coding, the power amplifier, the transceiver which is responsible for generating the signal and also receiving signals to the mobile station and the rectifier. The power consumption of these components should be multiplied by the number of sectors when determining the power consumption of BTSs [8]. Within these components, the transceiver and the power amplifier is one per transmitting antenna. Other components such as the air conditioning and the microwave link when no fiber link is available for backhaul are common to all sectors. In theoretical based power consumption, analytical model is developed to estimates the power consumption of a base station. Though in some cases, the estimation never give the realistic power consumption but somehow approximations. [8], the model indicates that once the power consumption of individual components of the base station is known, the total power consumption could be evaluated. As a validation of their model, the power consumption of one sector base station with one antenna was found to be 761W. This could only be achieved when the power consumption of AC of 225W as specified in the paper is used. In a typical situation in Nigeria BTSs, most sites use two Air Conditioners (ACs), Incandescent Bulbs and more than one microwave unit. Therefore, there is need to modify the model proposed to suite the realistic situations in Nigeria.

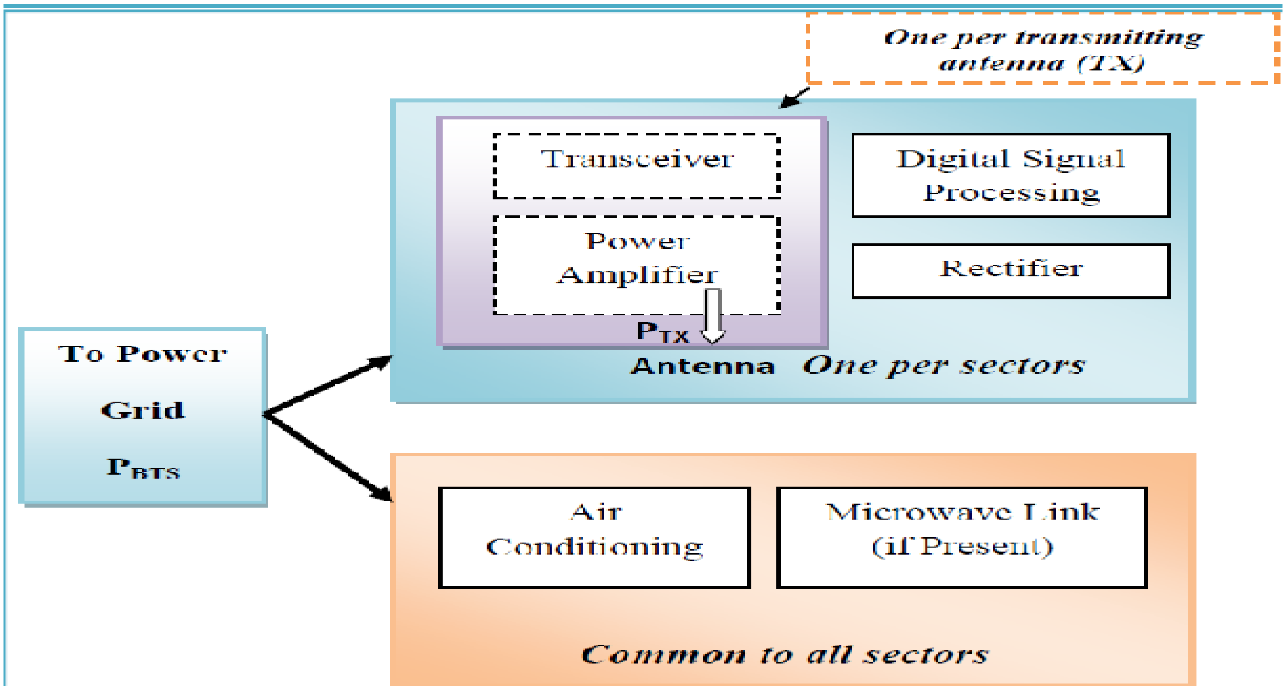

Fig 10: Block Diagram of BTS.

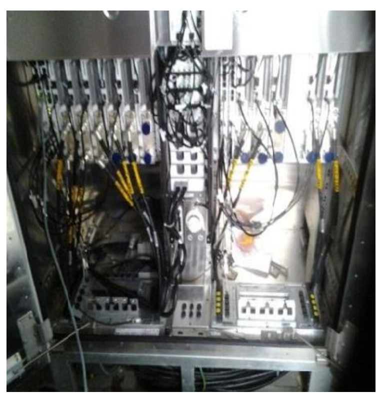

Fig 11: Top part of the inside Fig 12: Bottom part of the inside Fig 13: TRX's for 2G and Of a BTS cabinet
of a BTS cabinet 3G inside the BTS cabinet

Table 3: Power Consumption of Different Components of the BTS. [8].

EQUIPMENT'S	POWER	VALUE
Digital Signal Processing	PDSP	100w
Power Amplifiers (SISO)	η	12.8%
	P_{Amp}(Max)	156w
Power Amplifiers (MIMO)	η	11.5%
	P_{Amp}(Max)	10.4w
Transceiver	PTrans	100w
Rectifier	PRec	100w
Air Conditioning Units (A.C)	PAC	1170w
Incandescent Bulbs	PLB	60w
Microwave Links	PMicro	80w

Using the equipment's shown and listed in Figure 11 and Table 3, a model for BTS power was developed as shown below;

PBTS = PDSP + PTRX + PREC + PAC + PMICRO + PLB (1)

For a three (3) sector BTS, the TRX and DSP will be at least one (1) per sector. The TRX comprise of the Transceiver and the Power Amplifier.

PTRX = PAMP + PTRANS (2)

= ntrx/sector(PAMP + PTRAN)

Hence for the three (3) sectors excluding the microwave, Air conditioner and incandescent light bulb, the power consumed is;

PBTS = nsectors(PDSP + ntrx/sector(PAMP + PTRAN) + PREC) (3)

When the Microwave, Air condition and incandescent light bulb are added the model becomes;
PBTS = nsectors(PDSP + ntrx/sector(PAMP + PTRAN) + PREC) + Σ ACi + Σ micro Σ LBj (4)

This is the summation of the power consumption of all equipment that makes up the BTS. This relation may vary from one BTS to another as the equipment's or their number may vary depending on location, environment, etc.

n_{sector} is the number of sectors in the cell. $n_{trx/sector}$ is the number of transmitting antenna per

sector. PBTS , PDSP, PAmp, PTran, PRec, + Σ ACi, Σ micro, Σ LBj are the total power consumption of the following, the Base Transceiver Station, the Digital Signal Processing Unit, the Power Amplifier, the Transcievers, the Rectifiers, the Air Conditions, the Microwave and incandescent bulbs respectively. Where *n, l and m* represents the total number of AC's, microwaves in the BTS and bulbs in the site.

The total energy consumption for one BTS site (E_{BTS}) is given as;

$E_{BTS}=P_{BTS}*t$ (5)

Where, t - is the total time of use.

Using the values of Table 3 and assuming two (2) Air conditions, two (2) Microwave antennas and two (2) Incandescent Light Bulbs were used, the power consumed by a three (3) sector BTS per hour for Single Input Single Output (SISO) was calculated thus using (4):

Power Consumed By The Bts With Three (3) Sectors.

For One (1) TRX Per Sector

PBTS = nsector *(PDSP + nTR *(PAmp + PTran) + PRec) + Σ ACi + Σ micro ΣLBj
PBTS = 3(100 + 1(156 + 100) + 100) + 2(1170) + 2(80) + 2(60)
= 3(100 + 256 + 100) + 2340 + 160 + 120
= 3(456) + 2620
= 1368 + 2620
= 3988W
= **3.988KW**

For Three (3) TRX Per Sector

P_{BTS} = 3(100 + 3(156 + 100) + 100) + 2(1170) + 2(80) + 2(60)
= 3(100 + 3(256) + 100) + 2340 + 160 + 120
= 3(100 + 768 + 100) + 2340 + 160 + 120

= 3(968) + 2620
= 2904 + 2620
= 5524W
= **5.524KW**

For Six (6) TRX Per Sector

P_{BTS} = 3(100 + 6(156 + 100) + 100) + 2(1170) + 2(80) + 2(60)
= 3(100 + 6(256) + 100) + 2340 + 160 + 120
= 3(100 + 1584 + 100) + 2340 + 160 + 120
= 3(1784) + 2620
= 5352 + 2620
= 7972W
= **7.972KW**

N.B: Optimization was done by the use an Outdoor BTS unit which eliminates the use of Air conditioners and the light bulbs. This wouldn't be possible if the Shelter was used.

Optimized BTS Power For One (1) TRX Per Sector

PBTS = nsector *(PDSP + nTR *(PAmp + PTran) + PRec) + Σ micro
PBTS = 3(100 + 1(156 + 100) + 100) + 2(80)
= 3(100 + 256 + 100) + 160
= 3(456) + 160
= 1368 + 160
= 1528W
= **1.528KW**

Optimized BTS Power For Three (3) TRX Per Sector

P_{BTS} = 3(100 + 3(156 + 100) + 100) + 2(80)
= 3(100 + 3(256) + 100) + 160
= 3(100 + 768 + 100) + 160
= 3(968) + 160
= 2904 + 160
= 3064W
= **3.064KW**

Optimized BTS Power For Six (6) TRX Per Sector

P_{BTS} = 3(100 + 6(156 + 100) + 100) + 2(80)
= 3(100 + 6(256) + 100) + 160
= 3(100 + 1584 + 100) + 160
= 3(1784) + 160
= 5352 + 160
= 5512W
= **5.512KW**

BTS Power Consumed As A Function Of TRX Per Day Using (5)

For One (1) TRX Per Sector

PBTS = EBTS * t
= 24[nsector *(PDSP + nTR *(PAmp + PTran) + PRec) + Σ ACi + Σ micro Σ LBj]

= 24[3(100 + 1(156 + 100) + 100) + 2(1170) + 2(80)] + 12[2(60)]
= 24[3(100 + 256 + 100) + 2340 + 160 + 12[120]
= 24[3(1368 + 2500)] + 1440

= 24[3868] + 1440
= 92832 + 1440W
= **94.272KWHr**

For Three (3) TRX Per Sector

P_{BTS} = 24[3(100 + 3(156 + 100) + 100) + 2(1170) + 2(80)] + 12[2(60)]

= 24[3(100 + 3(256) + 100) + 2340 + 160] + 12[120]
= 24[3(100 + 768 + 100) + 2340 + 160] + 12[120]
= 24[3(968) + 2500] + 1440
= 24[2904 + 2500] + 1440
= 24[5404] + 1440W
= **131.136KWHr**

For Six (6) TRX Per Sector

P_{BTS} = 24[3(100 + 6(156 + 100) + 100) + 2(1170) + 2(80)] + 12[2(60)]
= 24[3(100 + 6(256) + 100) + 2340 + 160] + 12[120]
= 24[3(100 + 1584 + 100) + 2340 + 160] + 12[120]
= 24[3(1784) + 2500] + 1440
= 24[5352 + 2500] + 1440
= 188448 + 1440W
= **189.888KWHr**

Optimized BTS Power Consumed As A Function Of TRX Per Day For One (1) TRX Per Sector

PBTS = EBTS * t
= 24[nsector *(PDSP + nTR *(PAmp + PTran) + PRec) + Σ micro

= 24[3(100 + 1(156 + 100) + 100) + 2(80)]
= 24[3(100 + 256 + 100) + 160]
= 24[3(456) + 160]
= 24[1528 + 160]
= 24[1688]
= **36.672KWHr**

For Three (3) TRX Per Sector

P_{BTS} = 24[3(100 + 3(156 + 100) + 100) + 2(80)]
= 24[3(100 + 3(256) + 100) + 160]
= 24[3(100 + 768 + 100) + 160]
= 24[3(968) + 160]
= 24[2904 + 160]
= 24[3064]
= **73.536KWHr**

For Six (6) TRX Per Sector

P_{BTS} = 24[3(100 + 6(156 + 100) + 100) + 2(80)]
= 24[3(100 + 6(256) + 100) + 160]
= 24[3(100 + 1584 + 100) + 160]
= 24[3(1784) + 160]
= 24[5352 + 160]
= 24[5512]
= **132.288KWHr**

Solar Power Design for Macro Cell Sites

Solar power design for macro cell sites can be achieve by evaluating the total power consumption of all the equipment in each site which comprises of AC load and DC load. This total power consumption can then be used to design an alternative solar power system that will power the sites with the same capacity.
The total energy (E_{BTS}) required in (*Whr*) is defined as: $E_{BTS} = P_{BTS} * t$ ………………. (6)

Where P_{BTS} is the total power consumption per site which comprises of (AC + DC) loads and t is the operating time of the equipment. In Nigeria, on the average, there are 1885hours of sunshine annually. So the amount of available sunlight which is also known as the Isolation Value (IV) is 5.2hours/per day [9]. The Isolation Value is interpreted as the kilowatt–hours per day of sunlight energy that falls on each square meter of solar panels at tilt latitude. This Isolation Value varies as a function of location. Therefore, the required solar panel input S_{ip} is defined as

$$S_{ip} = \frac{\ }{\ } \qquad (7)$$

The number of solar panels required N_{SP} is given as:

$$N_{sp} = \frac{\ }{\ } \qquad (8)$$

Where P_{out} is the power output of each PV solar unit; this output power varies depending on the type of product module and its rating. The number of PV panels needed for a three (3) sector, one (1) TRX per sector, optimized BTS is evaluated below;

$E_{BTS/Day} = P_{BTS} * t$

$= 24(1528)$

$= 36{,}672$WHr

Since the power source is to support the BTS for 5 days;

$E_{BTS/5Days} = 5(36{,}672)$

$= 183{,}360$WHr

Average PV panel exposure per day = 5.2Hrs

PV panel wattage $= \frac{\ }{\ } = 7052.31$W

Using 300W PV panels;

$N_{sp} = \frac{\ }{\ }$

$= \frac{\ }{\ } = 23.51$

24 PV Panels

Switch Mode Power Supply (SMPS)

The main purpose of the SMPS is to regulator the alternating current supply to direct current which is used to charge the batteries and also to control the charging of the batteries so they are not over charged or over drained.by the load.

Battery Bank Sizing

This is a major component of the SMPS. It is basically the batteries that store charge that is used to power the BTS equipment that runs purely on D.C. In solar design, deep cycle batteries are used because these batteries are designed to be charged and discharged over a long period of time. They are not the same as car batteries which provide a large amount of current for a short period of time.

Fig 14: View of a Battery

To calculate the battery size required to provide for days of back-up in the event where there is no sun, the battery bank needs to be rated as follows:

(9)

Where;

n is the days of Storage i.e. period of back–up, this depends on the number of days you want the battery bank to support your load when other sources of power fails.
V_S is the operating voltage of the battery which varies with the capacity of battery to be used.
η is the efficiency after system losses i.e. depth of discharge of the battery, of which the maximum for deep cycle battery is 80%. This implies that the amps hours of battery storage required is given as;

B_{AHR} = (10)

There are many sizes of batteries available in the market, some of which include: 12V/100Ah, 12V/200Ah, 12V/250Ah, 24V/100Ah, 24V/150Ah, 24V/200Ah, 48V/100Ah, 48V/200Ah, 2V/1000Ah, etc. The choice of battery rating determines the number of batteries to be used, in order to minimize the number of batteries and available space, it is recommended to use high capacity batteries. Considering the capacity of battery to be use, the number of storage batteries required can be determine as:

N_{BTR} = (11)

Where, N_{BTR} is the number of batteries to be used I_b is the current rating of the battery chosen is the required amp hour of battery storage.

Batteries can be in series or parallel. [9].

N.B The battery bank of a BTS is expected to support the BTS for a period of at least 5days, per adventure there is power supply failure. Using the evaluation for average power of three (3) sector, one (1) TRX per sector, optimized BTS the number of PV panels and batteries is evaluated thus; Since the battery can only discharge 80% of its energy, actual battery power needed is;

$E_{BTS/5Days}$ = 183,360WHr

$E_{BTS/5Days(Actual)}$ = * $E_{BTS/5Days(Actual)}$ = 183,360

$E_{BTS/5Days(Actual)}$ = * 183,360WHr

= 229,200WHr.

From (11) N_{BTR} =

= **= 1,146 Batteries.**

To reduce the space occupied and bulky nature of the batteries, battery of much higher amperage (15,000A) was used. Hence number of batteries becomes;

N_{BTR} = = 15.28 ≈ **16 Batteries**

IV. SIMULATION RESULTS FOR POWER AND ENERGY CONSUMPTION OF THREE SECTORS SITE BEFORE AND AFTER OPTIMIZATION.

The power and energy consumption for a three sector site before and after optimization has been evaluated above and simulated using MATLAB, the result is shown in Figure 16. The values in Table 2 were used and it was assumed the site has two (2) ACs, two (2) bulbs and two (2) microwave units. Eqn. (4) was used to calculate the average power consumption before and after optimization. After optimization, (no AC's and bulbs were used). From Figure 16, it was found that the average power consumption for the site increased with increase in the number of transceivers per sector. It is note-worthy that an increase of 768W per transceiver was recorded. The power consumption for the site with 1TRX per sector was found, to, be 3.988KW. This increased to 5.524KW, and, 7.972KW, respectively, for 3TRX and 6 TRX representing 25.96% and 44.32% increase. When optimized, the power consumption for the site with 1TRX per sector was found to be 1.528KW and 1.0912KW respectively for SISO and MIMO representing 61.68% and 72.64% decrease. The energy consumed, as a function of the number of TRX per sector, and duration of power supply, for, three sector site was evaluated and simulated using MATLAB. Each component is assumed to operate for 24hrs/day except for the light bulbs which provides lightning for 12hrs/day (during the night periods). The result is as shown in Fig.16 was-used to evaluate the daily energy consumption for the site. It was noted that, the energy consumption increased in similar-vein with increase in the number of TRX in the site. For three sector sites, the energy consumption for 1TRX per sector was found to be 94.272KWh/day. This increases the power to 131.136KWh/day and 189.888KWh/day for 3 TRX and 6 TRX per sector respectively, representing 29.17% and 50.18% increase in energy consumption. The Power consumed by a six(6)sector site can be evaluated by substituting six (6) for number of sectors in (5).

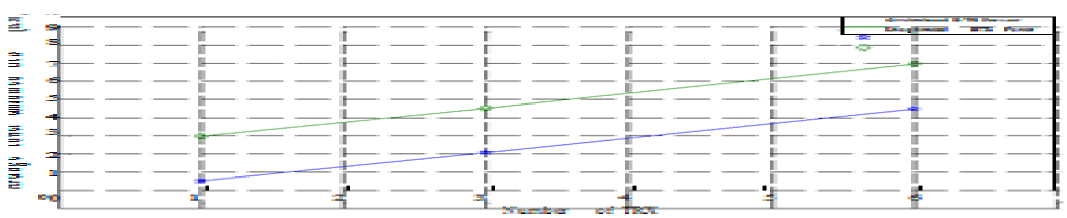

Fig 15: Average Power Consumed in Kilowatt with the Number of TRX per Sector.

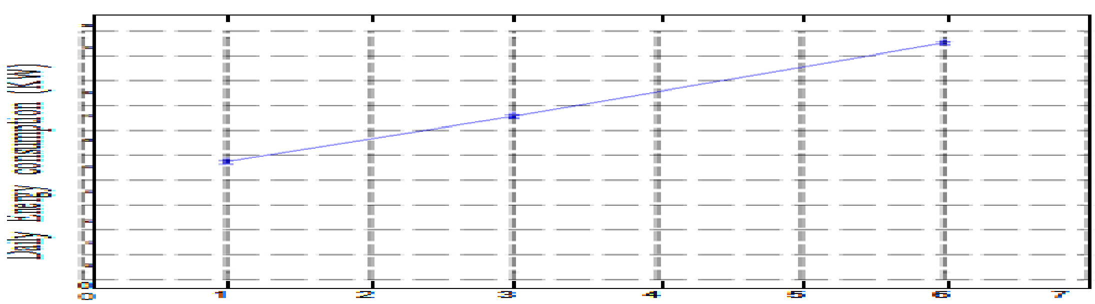

Fig 16: Daily Energy Consumption in Kilowatt Hour as Against the Number of TRX per Sector for Three Sector Site.

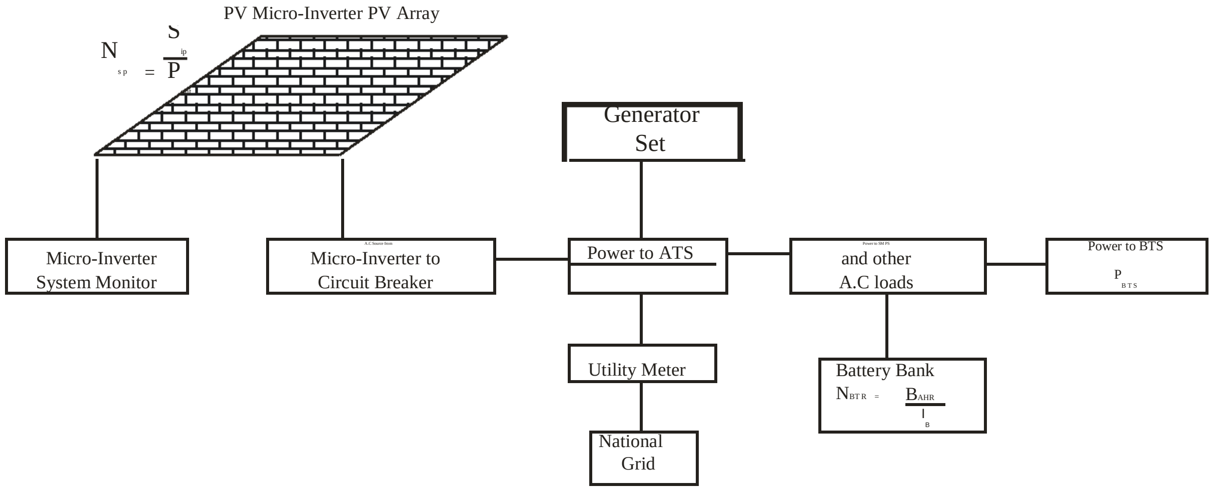

Fig. 17: Block diagram of the designed PV Micro-Inverter System integrated into BTS Power Supply.

Note: The micro inverter is mounted behind each panel and the A.C output from various panels is then connected in parallel to the breaker from where it feeds the ATS and the Grid. The ATS in turn feeds the SMPS and the A.C loads.

V. CONCLUSION

In this paper, an overview of integrating solar energy as an alternative renewable energy to power cell sites in mobile cellular systems was reviewed. The average power consumption for three (3) sector site was evaluated to be 3.988KW, 5.524KW and 7.972KW respectively for one (1), three (3) and six (6) TRX per sector. Optimization strategies to reduce the power consumption was deployed leading to a drop in average power consumption to 1.528KW, 3.064KW and 5.512KW respectively for one (1), three (3) and six (6) TRX per sector. Hence, solar power solution for both the optimized and non-optimized site has been evaluated.. Analysis of results shows that, the average power consumption for the site increase with increase in the number of transceivers per sector. It was also found that, the number of required solar panels and batteries for both optimized and non-optimized sites increased with increase in number of TRX per sector. Grid tied Solar power system is not advisable to be operated in Nigeria for now because power supply on the grid is not constant. Anytime there is no power on the grid nothing can be fed to it hence it is only applicable in countries where the power supply from the grid is constant. For this reason another switching system is incorporated into the main breaker that cuts supply to the grid when there is no power on the grid.

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