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Assessment of Wireless Network Reliability Based on Evaluation of Power Model Robustness

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ABSTRACT

This paper presents the assessment of the Power system model on the North West Region section of Air Tell Nigeria network for a period of one year and the reliability of the power subcomponents was determined. Analytic Model of the Operating Power setup at Hierarchical sites is described. The Quantitative Reliability models of each of the subsystem in the Power System are formulated based on the redundancy topology of the subsystem .Assessment of the Impact of variation in reliability parameter under optimal environmental condition was discussed. Verification and the validation of the reliability standards of power subsystem were elaborated. Criteria for the appraisal of the effectiveness of the Power Model and recommendation for the efficiency of Power Model were provided.

Keywords : Reliability, Traffic Capacity, Hierarchical Site, Load Demand, Automatic Transfer Switch (ATS)

1.0 INTRODUCTION

The challenge of poor availability and dependability of public power amidst mobile network expansion in many African Countries has compelled the exigency for supplementary power infrastructure at GSM sites to support the operation of base station equipment and network transmission so as to guarantee network reliability and minimize the impact of network failures due to power outages on subscribers in these Countries. Under such constraining conditions, GSM base stations not only dropped down voltage from utility transformers on Public power grids but require the support of standby Generators and backup battery systems to power the transmission and base subsystems at a base station site in case of failure of public power supply. In some operating cases, power reliance on Public Utility Grid is totally absent and Power Generation on site has to be completely dependent on Generators and standby battery backups to enable operators sustain ubiquitous and maximal availability of mobile network services. Meanwhile, the operational reliability of the transmission and base station subsystems load at each site is dependent on the efficiency and performance of the operating power system model at each site as well as the conditions of their operating environment. Moreover, GSM base stations are hierarchical in nature and power failure in some backbone or hub sites may result in network outages on dependant sites. A recent study on the reliability of GSM network power system conducted on the North West region of Airtel Nigeria Telecommunication Networks evaluated and summarized the criteria for the efficiency of the power model to sustain network reliability and guarantee customer Quality of service under such condition of public power absence or unreliability.

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2.0 STRUCTURAL COMPONENTS OF THE NETWORK

GSM Network is hierarchical in nature with signal and service transmission enabled from a Switch site along backbone trunks that constitute nodal backbone sites linked in a bus through Fibre or microwave connectivity. Traffic capacity are demultiplexed and dropped down into major hub sites that cross connect to other smaller hub sites or terminal sites. Switch sites often consist of equipment such as Mobile Switches (MSC) and Media Gateways for call control and switching, and transmission equipment like high capacity SDH Radios or DWDM to facilitate connectivity along backbone trunks, which are partitioned into a number of hops ,to Base Switching Controller(BSC) collocated hub sites or other switch sites. Backbone sites consist predominantly of transmission loads such as backbone SDH Radios and multiplexers that enable the cross connect and the add and drop of traffic to hub sites or provide the continual connectivity of signal and service traffics along backbone trunk from Switch sites to BSC collocated hub sites or other switch sites. In most cases, inter MSC backbone trunks support very dense traffic and are mostly Fibre connectivity backbones while backbone trunks between a Regional MSC base station and district BSC base stations are often microwave backbones. Hub sites are moderate traffic capacity sites that contain transmission equipment such as PDH or lower capacity SDH radios and multiplexers that provide transmission access to smaller hub sites or terminal sites. Terminal sites are single site depending on a hub site for signal and service connectivity. Terminal site has a base transceiver for wireless service transmission and an access radio only for feeding of signal and service from an adjacent hub site along line of sight without further extension to another site. In most cases, each of the hierarchical sites is collocated with a Base transceiver station (BTS) to enable wireless service transmission and reception on a mobile phone within the area. Each hierarchical site, therefore, has transmission and base subsystem loads that are run on a common power system and integrated on a power busbar that gives room for load prioritization, flexibility of automatic switching and load disconnection during critical power episodes. Therefore, the establishment of call between two parties on a GSM network would require the origination and the termination of signal from the Mobile Stations (cell phone) through the MSC station and along backbone trunks and cascaded links such that a total power outage along any participating hub site or backbone sites may result in network failure between the calling and called parties. Therefore, under a conservative assumption of ideal transmission and base subsystems with no intrusive fault at hierarchical sites, the operational reliability of the transmission and base station subsystems load at each site and, thus, the reliability of the network would depend on the efficiency and the performance of the power system model operational at each site as well as the conditions of their operating environment. The stability of the power subsystem and the redundancy scale of the subsystem in the power model are technically required to eliminate total outage or failures in the form of current and voltage surges that could lead to transmission and base subsystem equipment malfunction, failure or shutdown resulting from device overheating and distortion which could impair network reliability. Hence, informed the need for the evaluation of a power system driven network reliability.

For ease of challenge of GSM network site diversity and complexity, the sites in the network under study are classified into structural hierarchical components as integrated switch sites, integrated hub sites and terminal end sites based on the diversity of load support on a common power infrastructure at a site. The power requirement to support onsite loads, the traffic capacity, and the dependent col-located and the remote load compositions of each hierarchical site of the network under the study are summarized in Table 1.0.

Table 1.0: Load Demand and Load Distribution at Hierarchical Integrated Network Station.

Hierarchical Site	**Traffic Types**	**Traffic Capacity**	**Transmission Station**	**Load Demand**
Integrated switch site	Inter MSC,BSC and BTS traffics	Platinum ≥1000Earlangs	MSC, BSC and BTS load stations	300 kVA
Integrated backbone site	Inter MSC,BSC and BTS traffics	Gold 500≤Erl<1000	BSC,≤15BTS load stations	30 kVA
Integrated hub site	Inter BTS and BTS traffics	Silver 100≤Erl≤500	≤10 BTS load stations	20kVA
Terminal end site	BTS traffics	Bronze≤100Erl	Single BTS load station	13kVA

Source: Statistical Survey on North West Region of Airtel Nigeria Limited, January, 2009

2.1 THE NETWORK POWER SYSTEM MODEL

In real sense, GSM base station sites are hierarchical and diverse in nature and the degree of power redundancy composition and subsystem redundancy mode for each station depend on the integration level of the site.Therefore, for ease of challenge of GSM network site diversity, the study adopted an analytic modeling approach and assumed a dominant power model operational at one of the integrated switch site ,KADMSS01, while carrying out comparative analysis of the power setup at the site with those at other sites in terms of topological structure and power subsystem redundancy scale.KADMSS01 is an integrated switch site base station which support collocated MSC , BSC and BTS loads simultaneously on a common power system infrastructure in the studied network .The dominant operating power model for the study is shown in Fig 1.0

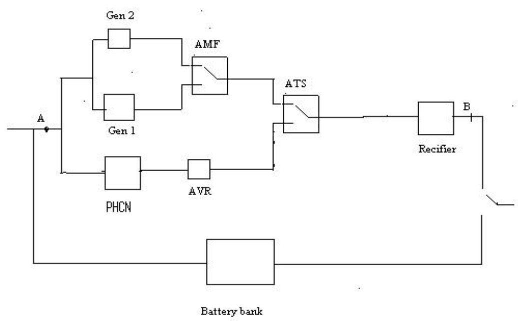

Fig 1.0 The Dominant Network Power system Reliability model

The dominant power model in the study is an integrated system with a collection of different power subsystems, which include a utility transformer from a Public Grid(PHCN), an automatic voltage regulator, two identical generators, a rectifier system, a battery bank, an automatic transfer switch, and automatic main failure, all interfaced in a definite topological structure shown in Fig 1.0 with redundancy scale that tolerates faults, allows for operation handover, and permits some degree of equipment downtime before restoration to optimal efficiency. The identical generator units are connected in a standby configuration such that the generator-set operation are changed over for a configured interval of time (often every 12 hours),when Public Power supply fails, through the aid of the Automatic Main Failure (AMF) unit which is composed of plastic case electromechanical relay switches. The output of the AMF is interfaced with the Automatic Transfer Switch (ATS) unit, which is a control switching relay that deactivates the operation of the generator set and gives upper priority to public power feeding only on availability condition such that the combined generator set forms a standby topology with the public power AC supply. The conventional public power equipment is cascaded with an Automatic Voltage Regulator (AVR) which stabilizes the supplied output AC voltage, frequency and phase and passes them within equipment utility level.

The regulated AC voltage from the stabilizer is fed into a logic controlled electronic Rectifier embedded with flexible regulation system. The rectifier consists of a specific number of identical modules that are connected in parallel to the DC power output bus bar and must have at least a certain number of the modules in active state to supply power to DC load while the battery bank is being charged through a DC-DC converter. Otherwise scenario of dc overload occurs on the rectifier unit and total load shutdown or shielding of low priority load is prompted depending on the power monitoring system configuration. Therefore, the failure of a certain number of the rectifier modules automatically commutates the power supply to the DC load to the standby battery bank.

2.1.1 REDUNDANCY TOPOLOGY OF POWER SUBSYSTEM ON THE MODEL

Assessment of the redundancy topology of each subcomponent on the power model was done to derive Quantitative reliability models that were used for evaluating the reliability standards of each major subcomponent from collected reliability parameters. The outcome of the reliability indices for particular redundancy topology of each subcomponent on the power model was used to appraise the

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impact of varying a particular reliability parameter while others are kept constant for the particular subcomponent.

3.0 Redundancy Topology and Assessment of Generator Reliability Standard.

The generator system on the GSM Power Reliability model is a two-identical generator standby redundancy system which is a model of an n-identical generator standby redundancy system with n-1 redundancies. The Quantitative reliability value is given by [10].

$$R = e^{-\beta t}\left(1 + \beta t + \frac{\beta^2 t^2}{2!} + \cdots \frac{\beta^{n-1} t^{n-1}}{(n-1)!}\right) \qquad \mathbf{1}$$

With an added weight function which has value is given as

$$w_{gen} = \left(\frac{\beta^{n-1} t^{n-1}}{(n-1)!}\right) \qquad \mathbf{2}$$

this predicts the inherent behavior of the reliability with sequential increase in the number of generator unit, n, on the system. n is an integer representing the number of generator units in the system, and β is the failure rate, such that $n \geq 2$.It was observed that

$$\lim_{n\to\infty} w_{gen} = \lim_{n\to\infty}\left(\frac{(\beta)^{n-1} t^{n-1}}{(n-1`)!}\right) = 0 \qquad 2.1$$

For a value $0 < \beta < 1$

and if (2.1) is rewritten as

$$R_{gen} = e^{-\beta t}\sum_{i=0}^{n-1} \beta^i t^i / i$$

Then $R_{gen} \to 1 \, as \;\; w_{gen} \to 0$

In the assessment of the impact of varying the number of redundancies in a generator standby system, the diminishing trend of the value of the Generator added weight function in Table 2.0 shows that the reliability index of the power system would be maximized with increasing number of unit generator while other conditions remain constant. In contrast, the configured standard service operation period per unit Generator would be shorter with enhanced availability index as the required operational uptime per unit generator would be less on the standby system. This is to imply that excessive strain would be reduced on each unit Generator on the standby system with increasing number of static reserve standby units in the system as the operation service time per unit is reduced. Thus, the total availability of the Generator standby system would be maximized for increasing number of unit generator and could tolerate a number of unit failure .The trend of the reliability result of the generator standby system is an evidence of reasons why long-term downtime of a unit generator failure is not much tolerated on the two-generator system as delay in optimum restoration would drastically strain the reliability of the generator redundancy system

Table 2.0 the Impact of the Variation of Number of Redundancies in a Generator Standby System

No.of Generator unit N	Failure rate β (10^{-3}hr^{-1})	Optimal operating Temp (^{o}C)	Reliability index of Generator set R	Weight of the series for the last n^{th} term w_{gen}
2	4.00	70	0.9999	0.004
3	4.00	70	0.9999	0.000008
4	4.00	70	0.9999	0.000001067
5	4.00	70	0.9999	1.066666667 ϵ-11
6	4.00	70	1.0000	8.533333335 ϵ-15

Source: Statistical Survey on North West Region of Airtel Nigeria Limited, January, 2009

In a power reliability system, the choice of the value of n is dependent on the maintainability, repair rate, the presence of alternative power supply redundancy and cost considerations. The value of the instantaneous failure rate is dependent on the lifecycle of the generator, the frequency of repair, the rate of part replacement, and ambient conditions. The Output Power Rating for each unit generator in the standby system is often above the load demand on site to exceed a certain load factor threshold and avoid Generator overload shutdowns that may result from base station load expansion during network capacity expansion activity.

3.1 Redundancy Topology and Assessment of Rectifier System Reliability Standard

The rectifier system on the GSM Power Reliability Model is a partial active redundancy system with an n-identical rectifier module and r-least number of active modules for the functional operation of the system. The number of least functional active module required for the operation of the system depends on the installed transmission and base subsystem DC load capacity at the network site and it is configurable. Therefore, the scale of redundancy of the modules for particular rectifier system varies for hierarchical station and has to be above certain load factor threshold to avoid DC overload shutdown on the rectifier system. This scale is therefore specified by the Firm’s standards that are driven by economics. The distribution of the rectifier module for hierarchical site at optimum efficiency in the studied network is presented in Table 3.0

Table 3.0: Rectifier Modules for hierarchical network site

Hierarchical site	**No. of modules per rectifier stand**	**Least number of active modules**
Integrated switch site	24	16
Integrated backbone site	16	8
Integrated Hub site	8	4
Terminal End site	8	2

Source: Statistical Survey on North West Region of Airtel Nigeria Limited, January, 2009

The reliability index of the partial active redundancy rectifier system with n rectifier modules and configured with r minimum rectifier modules at optimal operating temperature and conditions is expressed as [10]

$$R_{rec} = \sum_{i=0}^{n-r} \binom{n}{i} (1-R)^i R^{n-i} \qquad 3$$

This can be expanded as:

$$R_{rec} = \binom{n}{0}\left(1-R\right)^0 R^n + + \cdots \binom{n}{n-r}\left(1-R\right)^{n-r} R \qquad 4$$

Where R the Reliability is index of a unit module and is expressed as

$$R = e^{-\beta_{rec} t} \qquad 5$$

r is the least number of active for the functional operation of the rectifier system and β_{rec} is a unit Rectifier module failure rate and t is the observed time interval.

In the assessment of the impact of varying number of active module redundancies, it could be deduced from Table 2.4 that the reliability index of the system gradually increases and then peak at unity while increasing the number of active module redundancies, above certain value. Therefore the absolute standard availability index of the rectifier system would also increase with increase in the number of redundancies of the rectifier module. This justifies the installation of greater rectifier module redundancy at higher integrated hierarchical site for optimum efficiency. The trend of the reliability results in Table 4.0 is an indication that the partial redundancy system can tolerate redundancy reduction to some certain critical thresholds without much impact on the reliability value. Therefore, the partial redundancy system can tolerate some degree of delay before restoration to optimum efficiency in the event of some unit failure provided the number of active modules is above certain critical threshold

Table 4.0: Impact of Variation in the Number of Active Module on the Rectifier System Reliability Standard

N	β_{rec}	least number of active module	Optimal operating Temp	R_{rec}
6	$0.04/10^3$hr	4	20^0C	0.99999999999871900000000000000
8	$0.04/10^3$hr	4	20^0C	1.00000000000000000000000000000
10	$0.04/10^3$hr	4	20^0C	1.00000000000000000000000000000
12	$0.04/10^3$hr	4	20^0C	1.00000000000000000000000000000
14	$0.04/10^3$hr	4	20^0C	0.99999999999999991645130100088

Source: Statistical Survey on North West Region of Airtel Nigeria Limited, January, 2009

3.2 Redundancy Topology of Battery Bank System

The battery bank at GSM base station is an n-identical standby string of m-series connected batteries. The m-series connected battery is a -48V combinatorial system. The topology of the redundancy mode of the battery bank is shown in Fig 2.0

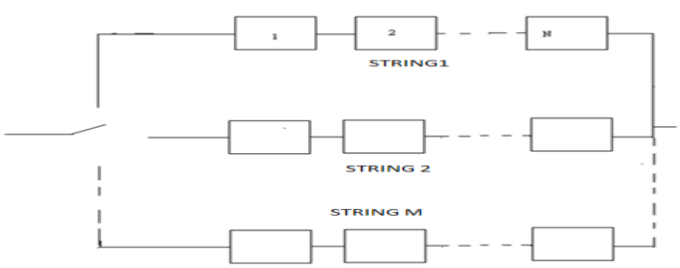

Fig.2.0 Reliability model of the battery bank at networks

The number of standby string redundancies and series unit battery per string for the battery bank system vary for hierarchical network site and the distribution for the network under study is presented in Table 5.0

Table 5.0: Distribution of backup Battery for hierarchical network Site

Hierarchical site	No. of String Row	No. of Series Battery Per String	Unit Battery Voltage Rating	Sustenance Time
Integrated switch station	16	4	12V	24hrs
Integrated	8	4	12V	12hrs

backbone site				
Integrated hub site	4	4	12V	10hrs
Terminal end site	2	4	12V	8hrs

Source: Statistical Survey on North West Region of Airtel Nigeria Limited, January, 2009

The reliability index of the battery bank with n strings and m-series battery per string at constant temperature and operating condition is given by equation 6.

$$R = e^{-m\beta t}\left(1 + m\beta t + \frac{(m\beta)^2 t^2}{2!} + \cdots \frac{(m\beta)^{n-1} t^{n-1}}{(n-1`)!}\right) \qquad \mathbf{6}$$

The m-series connected battery is a -48V combinatorial system. The choice of the value of the number of series battery per string, m, may depends on battery bank design trends, scalability and availability of unit battery, space and cost considerations. For most practical cases on the GSM power model, m=4 in which each battery unit has a rating of 12V or m=8 for which battery unit has a rating of 6V.Therefore,the scalability of the battery rating, is a major factor that affects the reliability of the series combinatorial system provided all installation conditions are intact.

In the assessment of the impact of unit battery rating in the -48V combinatorial system for a constant number of strings, failure rate and at optimal temperature and environmental condition, the outcome of battery bank reliability index in Table 6.0 was found to be greatly high for m=16 in which 3V rating battery units are used on the battery system; for m=4 in which 12V rating battery units are used on the battery bank system; and for m=8 for which 6V rating battery units are used on the battery system at constant failure rate, temperature and environmental conditions. Therefore, the reliability results in Table 6.0 reveal the significance of scalability consideration on the battery bank redundancy design planning when all other parameters are kept constant.

Table 6.0: Impact of Battery scalability on Battery bank Reliability Standards

M	**N**	$\boldsymbol{\beta}$	**Temp**	$\boldsymbol{R_{batt}}$
2	8	$1.0/10^3$hr	20°C	0.99999999999999960044349227936345
4	8	$1.0/10^3$hr	20°C	1.00000000000000000000000000000000
6	8	$1.0/10^3$hr	20°C	0.99999999999999973361023861291864
8	8	$1.0/10^3$hr	20°C	1.00000000000000000000000000000000
10	8	$1.0/10^3$hr	20°C	0.99600798934399141845594945142228
12	8	$1.0/10^3$hr	20°C	0.99999999999999945336802732632609
14	8	$1.0/10^3$hr	20°C	1.00000000000000000000000000000000
16	8	$1.0/10^3$hr	20°C	1.00000000000000000000000000000000

Source: Statistical Survey on North West Region of Airtel Nigeria Limited, January, 2009

In similar manner, the Firm design with variation in the number of battery string for hierarchical levels of network site provide a basis for the assessment of the impact of the variation in the number of standby strings on the reliability standard at hierarchical network stations. The impact of the variation in the number of standby strings on the reliability standard at hierarchical network stations was assessed with the assumption of a constant number of identical series batteries at constant temperature and environmental conditions. The result was presented in Table 7.0

Table 7.0: Impact of the Number of Standby Strings on the Battery bank Reliability Standards

M	N	β	Temp	R_{batt}	W
4	2	1.0/10^{3}hr	20^{o}C	0.99999202130136796800000000	4.0 ϵ-3
4	4	1.0/10^{3}hr	20^{o}C	0.99999999989368271607911	1.06 ϵ-8
4	6	1.0/10^{3}hr	20^{o}C	1.00000000000000000000000	8.53 ϵ-15
4	8	1.0/10^{3}hr	20^{o}C	1.00000000000000000000000	3.25 ϵ-21
4	10	1.0/10^{3}hr	20^{o}C	1.00000000000000000000000	

Source: Statistical Survey on North West Region of Airtel Nigeria Limited, January, 2009

The running of sites loads on battery power often occur at critical power episode, when there is a complete AC power outage or complete rectifier system failure such that the supply of power to network transmission load at an integrated hierarchical site is completely dependent on the battery bank. Under this circumstance, automatic low voltage load disconnections occur sequentially on hierarchical transmission load at an integrated network site resulting in increasing traffic loss until complete network downtime occur at the site when the faulty AC unit is not urgently restored within battery runtime event. The level of traffic drop increases and the percentage of customer impacted increases due to more loads disconnection with depreciating battery bank voltage during this critical power episode.

4 CONCLUSSION

In the course of the study, it was ascertained that the reliability configuration standard on the GSM power system is dynamic because it can easily be varied to suit the desired reliability standard of the operator. It is driven by changes in organization economic or operational environments, ergonomics, geographic and climatic conditions. It was discovered that the reliability standards of the power subcomponents of the GSM networks studied are within reasonable robust level that is not compromised by cost considerations that might undermine reliability value and result in excessive critical outages events.

It could be concluded that in the assumption of optimal working conditions of all the subsystems and ideal maintenance practice by the firm, then, the reliability standards of the GSM power model would greatly depend on topological design factors such as the:

1. Redundancy mode of each subcomponent.

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2. Degree of redundancy of each subcomponent.
3. Failure ratings or the lifecycle of the subcomponent units
4. Scalability of the subcomponent unit used on the system

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