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COMPONENTS IMPORTANCE ANALYSIS OF PLC NETWORKS FOR THE POWER HOLDING COMPANY OF NIGERIA

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ABSTRACT

This paper has analysed the reliability importance of power line communication (PLC) system connected to the Nigerian national electricity grid for a period of eleven (11) years. Birnbaum's component importance technique is used to derive the components' reliability importance functions of phase-to-earth, phase-to-phase and inter-system PLC couplings. A comparative analysis is made on the components' reliability importance of the existing PLC system in the power Holding Company of Nigeria (PHCN), phase-to-phase and inter-system networks. The study has shown that the components' importance of PLC systems is a function of the coupling methods. The outputs of the analysis are then compared, with suggestions and recommendations made.

Keywords: Power Line Communication; Components Importance Analysis, Reliability Block Diagram

1.0 INTRODUCTION

Power line communication (PLC) technology has been around for many years since the power line carrier systems were being used on electric transmission and distribution networks to carry digital data and voice. For example, voice transmission via power line carrier dates back to the 1920s (Robert, 1993). The PLC-based communication systems are attracting attention because PLC is a promising technology for deploying communication networks in remote places, taking advantage of the existent electrical infrastructure (Garcia-Baleon and Alarco-Aquino, 2009). The vast infrastructure already in place for power distribution means that these services will be available to more users than any other alternative (in particular, helping to overcome the urban/rural 'digital divide'), with no disruption to operation of power systems, upon installation (Sophie, 2006).

Power line communication technology allows the transmission of data over the same lines used to transmit electric power and has been heralded as the 'next big thing' in communications (Abubakar, 2011). PLC technology can be deployed worldwide anywhere there is an electrical network. The pervasiveness of power line infrastructure creates an enormous opportunity for the providers of this technology on a global scale. In the United States alone there are approximately 125 million utility customers connected to power lines (Ambient, 2006).

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By the middle of May 2001, power line communication enabled deployment of commercial internet connection through wall socket with data rate of 2 Mbps (Deny and Ery, 2003).

In Power Holding Company of Nigeria (PHCN), power line communication system is used to provide voice and data communication for the protection of high voltage transmission lines connected to Nigerian grid. PLC is the main method of telecommunication in PHCN. By way of definition, PLC is a system of telecommunication whereby a carrier frequency (typically between 24 kHz to 500 kHz) is superimposed on a 3-phase high voltage transmission (typically between 33 kV and 330 kV in Nigeria) to convey information when such a high frequency signal is modulated. PHCN uses PLC as the major means of communication between different stations connected to the Nigerian grid. PLC components' importance is considered in this paper.

2.0 DETERMINATION OF COMPONENTS RELIABILITY FIGURES

A system reliability equation accommodates the system configuration and its behaviours, with the answer relying on how accurately the system configuration and its behaviours are understood, and what assumptions are made and adopted. It also relies on what modelling method and tools are used. In this paper the following assumptions are made:

*The reliability of each individual block is known or can be estimated,
*Only hardware failures are considered,
*All lines share the same semantics (type-less),
*Failures of blocks are statistically independent,
*Blocks are bimodal: they either operate fully or fail completely (degradation of service is not allowed for) and
*The power line communication system reliability is a function of reliability values of components that make up the system.

Given these assumptions, it is possible to calculate the reliability of the components that make up power line communication. The generic failure rate,, of each component that makes up the power line communication system is obtained from the Military Hand-book (US DoD, 1996). Exponential-time distribution model is assumed since the components' failure rates are assumed constant. It is one of the simplest distribution forms to actually calculate reliability value. The exponential failure density function $f(t)$ is defined by

$$f(t) = \lambda e^{-\lambda t} \qquad (1)$$

where λ t is operating time. The reliability function $R(t)$ is given by

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

The reliability equation for each component as a function of time is obtained by substituting the generic failure rate of each component into equation (2). Matlab programme is used in evaluating the reliability figures of the different componen ts, the output of which is presented in Table 1. In the Table, the subscripts have the following meanings: RT = receiver/transmitter unit, CO = coaxial cable unit, MX= matching transformer, CF = coupling filter, CC = coupling capacitor, PU = protection unit, LT = line trap, XL = transmission line.

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3.0 COMPONENTS' IMPORTANCE ANALYSIS (CIA)

One purpose of system reliability analysis is to identify the weakness in a system and to quantify the impact of component failures. The so-called "reliability importance (also called sensitivity analysis)," is used for this purpose (Xing and Amari, 2007). However, previous reliability analysis of different PLC couplings gives very little information about each individual component's contribution to the entire system reliability or failure. It is observed that some components contributed more to the network reliability. It should be obvious that some components in the PLC systems are more important than the other ones.

Table 1: PLC Component reliability figures (Abubakar, 2011)

Time (hours)	R_{LT}	R_{CC}	R_{PU}	R_{MX}	R_{CO}	R_{CF}	R_{RT}
8760	0.9851	0.9987	0.9973	0.9916	1.0000	0.9979	0.9999
17520	0.9705	0.9975	0.9947	0.9833	0.9999	0.9958	0.9998
26280	0.9560	0.9962	0.9921	0.9751	0.9999	0.9937	0.9997
35040	0.9418	0.9950	0.9894	0.9669	0.9998	0.9916	0.9997
43800	0.9278	0.9937	0.9868	0.9588	0.9998	0.9895	0.9996
61320	0.9004	0.9912	0.9815	0.9428	0.9997	0.9854	0.9994
70080	0.8870	0.9900	0.9789	0.9349	0.9997	0.9833	0.9993
78840	0.8738	0.9887	0.9763	0.9271	0.9996	0.9813	0.9992
87600	0.8608	0.9875	0.9737	0.9193	0.9996	0.9792	0.9992
96360	0.8480	0.9862	0.9712	0.9116	0.9996	0.9771	0.9991

The objective of component importance measure is therefore, to identify the components that should be modified, improved or replaced with higher quality ones. It indicates the improvement of the system reliability when the component under consideration has been replaced by a perfect component. The results from the component importance analysis are key contributors to the system design, tuning, and maintenance activities (Xing and Amari, 2007). Components importance analysis is vital to avoid economic, social losses and power outages in the country, hence the need to assess the components that make up the existing communication networks on the Nigerian 330 kV grid. This paper analyses the components that make up the PLC system in PHCN.

In order to get an efficient operation of the PLC system it is necessary to measure the relative importance that each component has in it. This importance depends on two factors: the allocation the component has in the system (first factor) and its proper reliability (second factor). Josep and Albina (2002) and (Xing and Amari, 2007), identified some of the models used in components importance analysis based on the type of system and assumptions made. Therefore, based on the assumptions listed Birnbaum's component importance is used which is defined by Josep and Albina 2002; Wendai *et al*, 2004; and Xing and Amari, 2007 as

$$I_K^B(t) = \frac{\partial R_s(t)}{\partial R_k(t)} = \frac{\partial F_s(t)}{\partial F_k(t)} \quad (3)$$

Where $I_K^B(t)$ is the reliability importance of the k^{th} component for B^{th} coupling circuit, $R_s(t)$ and $F_s(t)$ are the system reliability and unreliability at time t respectively; and, $R_k(t)$ and $F_k(t)$ are respectively the reliability and unreliability of component k at time t.

The Birnbaum importance measure (metric) of a component is independent of the reliability of the component itself. By the definition, $I_K^B(t)$ is the rate of increase (at time t) of the system reliability with respect to the component's reliability. It also measures the probability of a component being responsible for system failure at time t. The components importance for different couplings is considered as follows.

3.1 CIA of a Phase-to-earth Coupling Circuit

In phase-to-earth coupling circuit, failure of one component results in the failure of the whole network. Therefore, the reliability block diagram for the phase-to-earth coupling network is obtained using series reliability block diagram shown in Figure 1.

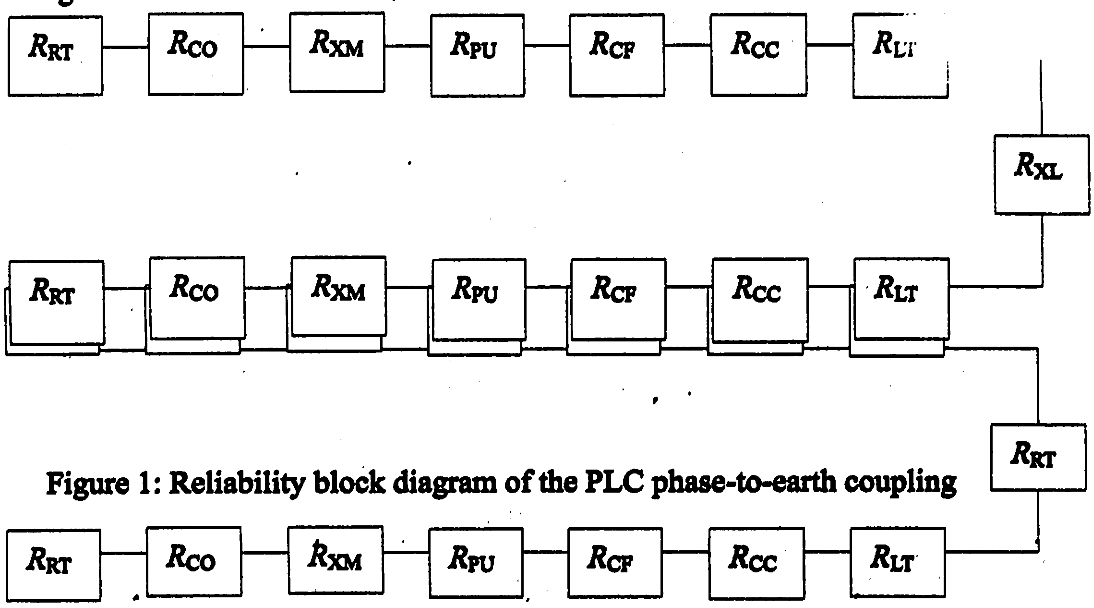

Figure 1: Reliability block diagram of the PLC phase-to-earth coupling

To determine the ranking of components that makes up phase-to-earth power line communication network, the reliability component of transmission line is assumed equal to 1. Thus, the reliability equation for the PLC phase-to- earth coupling system shown in Figure 1 is,

$$R^{PE} = R_{RT}{}^2 \times R_{CF}{}^2 \times R_{MX}{}^2 \times R_{PU}{}^2 \times R_{CO}{}^2 \times R_{CC}{}^2 \times R_{LT}{}^2 \quad (4)$$

The reliability importance of each unit that make up phase-to-earth coupling is obtained by substituting equation (4) into equation (3).
Thus, the Birnbaum importance of each component is obtained by substituting the reliability figures presented in Table 1 into Birnbaum's component importance equation of each component. The component ranking in phase-to-earth coupling is represented by Figure 2.

It is observed that the protection unit has the highest reliability importance, meaning that the unit has the highest influence on the system reliability. It contributed more to the system failure, transmitter/receiver unit, coaxial cable, coupling capacitor units, matching transmitter and line trap in that order.

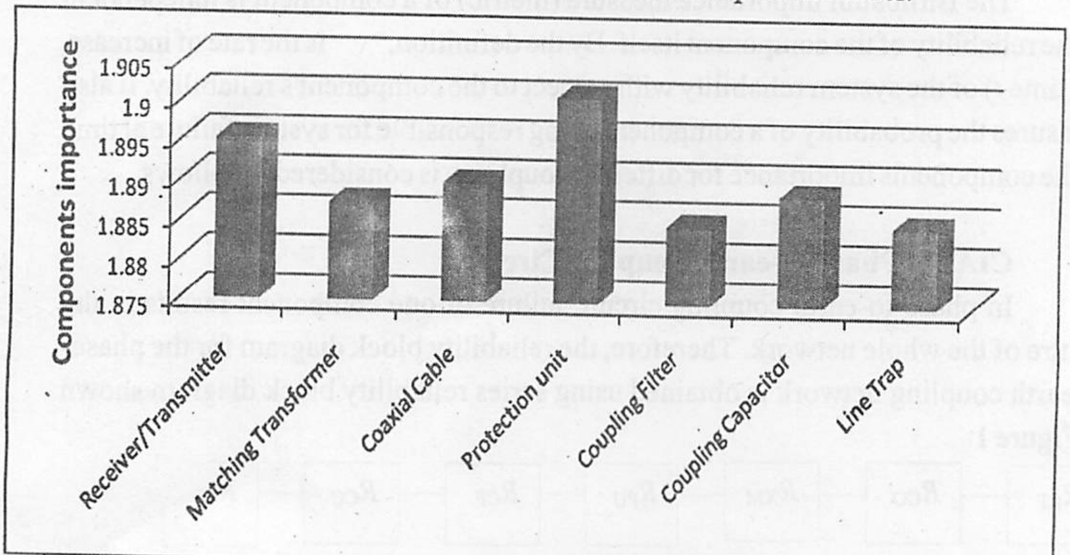

Figure 2: Components reliability importance for phase-to-earth coupling circuit

The result obtained followed similar pattern with the data collected from the National Control Centre Osogbo. In the data collected most of the failures are from the terminal equipment and not from the main PLC circuit. For the phase-to-earth coupling connected to the national grid the reliability of the network could be improved by replacing some components with those having higher reliability importance values, since the reliability importance of the components is a function of systems' reliability which, in turn, is a function of the type of PLC coupling. Therefore the reliability importance of the components depends on type of coupling.

3.2 CIA of a Phase-to-phase Coupling Circuit

The equivalent reliability block diagram of the phase-to-phase coupling circuit is represented by Figure 3. The network topology in phase-to-phase coupling is different from that of phase-to-earth coupling. The components ranking is therefore expected to be different. The reliability equation of the phase-to-phase is obtained using series and parallel theorems of Reliability block diagram. That is,

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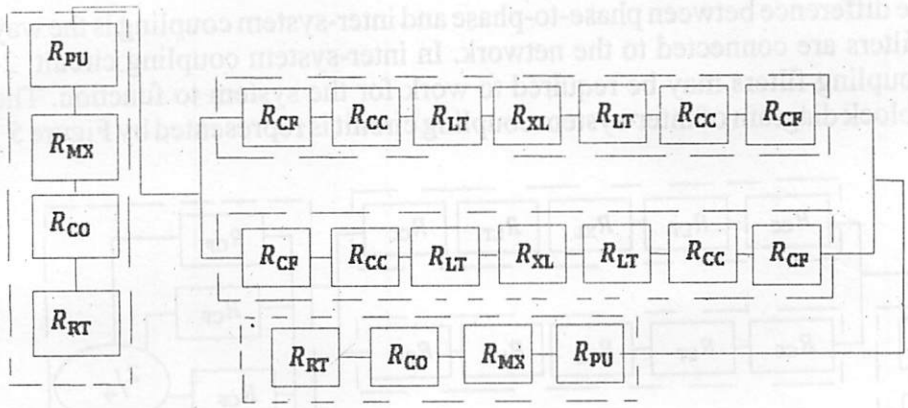

Figure 3: Reliability block diagram for power line communication phase-to-phase coupling

$$R_{pp} = \left(2\left[R_{CF}{}^2 \times R_{CC}{}^2 \times R_{LT}{}^2\right] - \left[R_{CF}{}^2 \times R_{CC}{}^2 \times R_{LT}{}^2\right]^2\right) \times R_{RT}{}^2 \times R_{MX}{}^2 \times R_{CO}{}^2 \times R_{PU}{}^2 \quad (5)$$

The reliability importance measure of each component that makes up the phase-to-phase coupling is obtained by substituting equation (5) into equation (3). Thus, the Birnbaum importance figures of each component is obtained by substituting the reliability figures presented in Table 1 into Birnbaum's component importance equation of each component. Microsoft Excel is used in determining component ranking figures. The component ranking in phase-to-earth coupling is represented by Figure 4.

In phase-to-phase coupling, matching transformer has the highest reliability importance measure, followed by line trap, receiver/transmitter, coupling filter, protection unit and coaxial cable in that order. In this coupling, the matching transformer is contributing the highest percentage to system failure. This means that topology of the network influences the contribution of components to the reliability of the network.

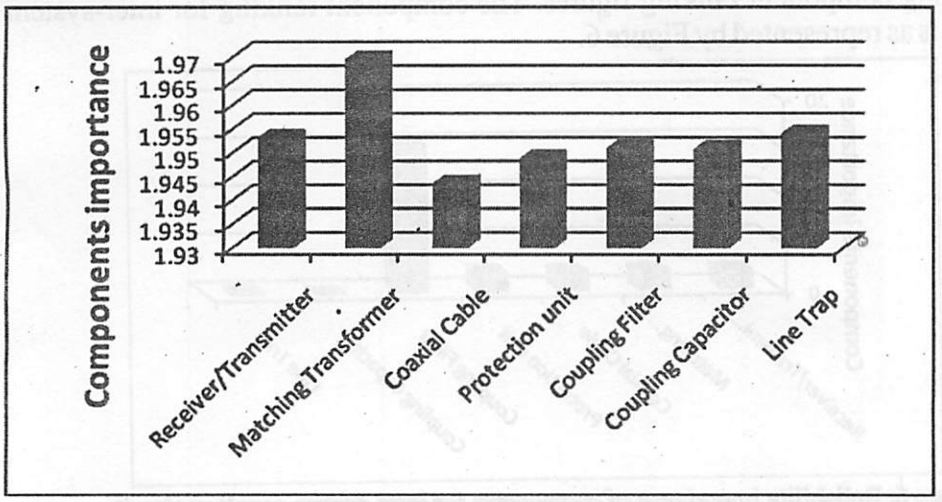

Figure 4: Reliability importance of components for Phase-to-phase coupling circuit

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3.3 CIA of Inter-System Coupling Circuit

The difference between phase-to-phase and inter-system coupling is the way coupling filters are connected to the network. In inter-system coupling circuit, 2-out-of-4 coupling filters may be required to work for the system to function. The reliability block diagram of inter-system coupling circuit is represented by Figure 5

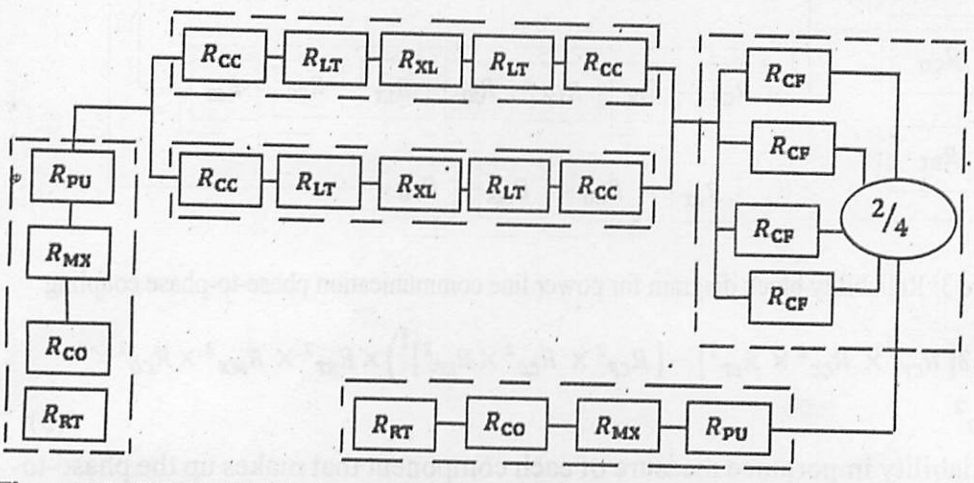

Figure 5: Reliability block diagram for power line communication inter-system coupling

The reliability equation for inter-system coupling is obtained by using redundancy, series and *m*-out-of-*n* models. The reliability equation is given by

$$R_{IS} = R_{RT}^2 \times R_{MX}^2 \times R_{CO}^2 \times R_{PU}^2 \times \left(6R_{CF}^2(1-R_{CF})^2 + 4R_{CF}^3(1-R_{CF}) + R_{CF}^4\right) \times \left(2\left(R_{CC}^2 \times R_{LT}^2\right) - (R_{CC}^2 \times R_{LT}^2)^2\right) \quad (6)$$

Components contribution to system failure is obtained by substituting equation (6) into equation (3). Thus, the Birnbaum importance figures of each component is obtained by substituting the reliability figures presented in Table 1 into Birnbaum's component importance equation of each component. Microsoft Excel is used in determining component ranking figures. The component ranking for inter-system coupling is as represented by Figure 6.

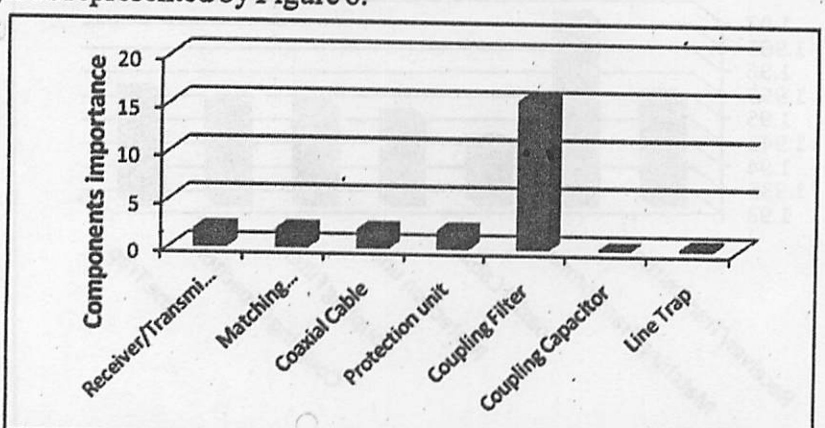

Figure 6: Reliability importance of components for inter-system coupling circuit.

The coupling filter unit is the highest contributor to the system failure in inter-system coupling, followed by matching transformer, protection unit, receiver/transmitter unit, coaxial cable, line trap, and coupling capacitor in that order of contribution to the system failure.

4.0 CONCLUSION AND RECOMMENDATIONS

The components' reliability importance is a function of the type of PLC coupling employed. In PHCN, most of the PLC network failures are from the protection unit and the receiver/transmitter during the 11 years under investigation. It is recommended that these units should be replaced with higher reliability components. This will also improve the reliability of the present PLC system in PHCN. Based on the results obtained, from this research, a recommended area of further research is to study the component importance for proper maintenance of the PLC system connected to the Nigerian national grid.

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