Nigerian Journal of Technology (NIJOTECH)
Vol. 37, No. 1, January 2018, pp. **209 – 215**

Print ISSN: 0331-8443, Electronic ISSN: 2467-8821
www.nijotech.com
http://dx.doi.org/10.4314/njt.v37i1.27

ASSESSING THE IMPACTS OF DISTRIBUTED GENERATION ON THE PROTECTION SCHEME OF A DISTRIBUTION NETWORK: TRANS AMADI 33 kV DISTRIBUTION NETWORK AS A CASE STUDY

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ABSTRACT
Protection scheme of a radial network fails in coordination when additional power source is provided to the network via distributed generator other than a single source of power. Trans Amadi, 33 kV radial distribution network in Port Harcourt, Nigeria, has manually operated isolators backing up circuit breakers at substation. This arrangement alone cannot overcome rising issues due to bidirectional/multidirectional flow of power in a radial network whenever distributed generators are connected. There is therefore, a need for a protection scheme to be adopted whose devices can "coordinate" as well as offer a reliable protection to the network. This paper proposes a protection scheme design using coordinated behaviours of relay-operated reclosers and sectionalizers, as well as manages the effect distributed generators has, in a radial network using fault current limiter. Proposed protection scheme show results of a good coordination, mis-cordination and an improved coordination, without distributed generator, with distributed generator and with a fault current limiter respectively.

Keywords: *distribution network, distributed generators (DG), protection scheme, coordination.*

1. INTRODUCTION

There exist three major levels in electric power system which includes generation, transmission and distribution. Electric power is conveyed from a central and remote source location (generation) to distant location for the end users via transmission and distribution networks with the distribution networks being the closest to the users. These distribution networks can be radial or ring but in most case traditional radial network is adopted due to its low cost, simple protection scheme, facilitates network stability and reduction in number of protective device [1, 2]. Radial network is a form of unidirectional power flow from source to load points. The power loss due to voltage drop in transmitting power to the consumer end and the cost incurred in building new transmission lines have led to the growing interest and wide acceptability of distributed generation.

DG requires use of large small size distributed generators within the radial network [3, 4]. DG can be categorized into direct current (d.c) power generators or alternating current (a.c) power generators [3] and distributed generator referred to in this study is the Trans Amadi gas fired alternating current generator.

These distributed generators when connected to the network, come along with the following benefits: improvement of network reliability and voltage profile, cheaper electric power supply, reduction of load supplied from a central source, increased network capacity, reduction in electric losses and environmental pollution [5 - 8]. But distributed generation penetration in a network is not without a cost as it gives rise to technical challenges whenever they are connected to a network. Studies have shown that the unidirectional flow of power in a traditional radial distribution network changes to bidirectional when distributed generator is connected [9]. Change in power flow impacts on the network in the following areas; reliability, operation, protection and control of existing power source and islanding operations [10, 11]. The impact on the existing protection scheme of network can also be broken down into areas such as protection blinding, decrease or increase in fault current due to DG removal or connection, sympathetic and abnormal tripping of protective devices [10].

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Also, protection scheme can be applied either or on both the feeder side and generator side in the network, requiring protective devices such as fuses, relays or reclosers [12]. This study centres on protection on feeder side of network in the presence of distributed generators through an efficient and reliable protection scheme. The complexity of a protection scheme depends on the nature of distribution network. While a closed loop (ring network) offers lots of benefits such as continuity of power supply and improved security compared open loop (radial network), the protection scheme of a closed loop is more complex than open loop. For instance, the use of pilot wires instantaneous protection for a closed loop network is a complex protection scheme [1] compared to the technique of inverse definite minimum time overcurrent protection (IDMT) and time graded overcurrent protection have been employed in the design of a protection scheme for a radial network with emphasis on the coordination of the protective devices. Moreover, most protection scheme ensures the coordination of protective devices in the distribution network. But most protective device coordination fails as well as its reclosing operation, due to changes in power flow, direction and magnitude of fault current contribution from the inserted generators in the network [6]. But this technical challenge of mis-coordination has been overcome through several proposed approaches as stated in literatures. Most solutions to these technical challenges have been summarized into wide area protection scheme, adaptive protection and communication/interaction between relay protective devices [13]. A combination of communication technology, distribution system automation and multi-agent based protection scheme has been used to solve the problem of coordination of protective devices in a network [14]. The technology of superconducting fault current limiter (SFCL) have been used to solve coordination problems of protective devices which can limit fault current contributions of distributed generators [15]. There is little or no power loss with this proposed method. But SFCL have inherent properties which affects the coordination of devices so that they get out of their initial setting values unless its resistances are carefully selected within accepted ranges. Through the use of fault current limiter (FCL) which is more cost effective than SFCL, incorporated in a protection scheme, fault current contribution from DG have been properly dealt with, leading to a more efficient and effective protection scheme whose devices are well coordinated [16].

Finally, the understanding of protective device coordination is vital as it involves the choosing of relay protective devices in relation to their time-current setting within the feeder length in order to isolate equipment and feeders from faults. This ensures that main protective device operate quickly in the event of a fault, otherwise a back-up device operates. Device coordination can also be referred to as selectivity. In this case, devices provide back-up protection to other zones of protection by delaying operation while at the same time operate as faster as possible within the main/primary zone of protection. This is possible using the technique of inverse time overcurrent relays which functions in such a way that as the operating time increase, then the current magnitude decreases. The whole essence of selectivity or coordination is to ensure maximum power delivery with minimum power system disconnection [17].

Based on the knowledge revealed in the above literatures and analysis, this study adopts the design approach presented in Abdi *et al.* [16]. In the work, a radial distribution network was considered and the design approach focused on a radial distribution network and his design approach is on coordination of protective device with inserted FCL that handles increases in fault level. This study also includes SIMULINK modeling approaches for protection scheme and the use of a programmable FCL. Also the programmable FCL makes the protection scheme more extensible to allow additions of future DGs with little or no modifications to existing scheme.

2. RESEARCH METHODOLOGY

Research Procedures/Algorithms

Perform short circuit study of distribution network with reference to the transformers connected and the results are used to perform relay setting.

Using the approach for determining operating times of protective devices carried out by Abdi, *et al* [16], model the operating times of proposed relays in distribution network, for a case without generators, using relevant mathematical equations.

Observe the sequence of operation of protective devices when a short circuit is applied to the buses, mainly at the junction of connection to the 33 kV distribution line [12]. This stage still lacks the presence of generators.

Observe the sequence of behaviour of the overcurrent relay devices when a fault current level is applied to the buses (as in the case above) but this time with the presence of a distributed generator (that is with the gas plant connected).

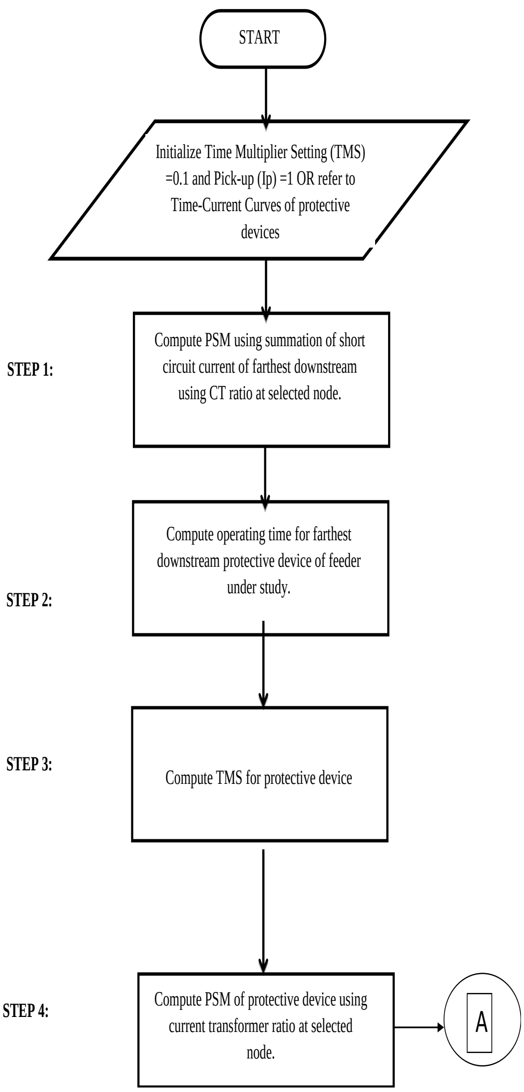
A single line diagram of 33 kV Transamadi distribution network from Oginigba link road to Ordinance roundabout, was obtained from PhED office (Port Harcourt Electricity Distribution). This diagram shows all distribution substation and ratings of the transformers installed.

A single line diagram of TransAmadi gas turbine/plant was obtained from Sahara group that presently maintain this independent power plant (IPP). This diagram constitute distributed generators as it shows all installed generators, circuit breakers (CB), step up transformers and auxiliary transformer.

Figure 3 shows a flow chart for determining the operating times of the protective devices within a selected feeder.

2.1 Case study of 33 kV Trans-Amadi Radial Distribution Network

A case study of 33 kV radial distribution network in Port Harcourt, from Oginigba link road to Ordinance roundabout of Trans-Amadi area with Trans-Amadi gas turbine (generators) was investigated [Figure 1].



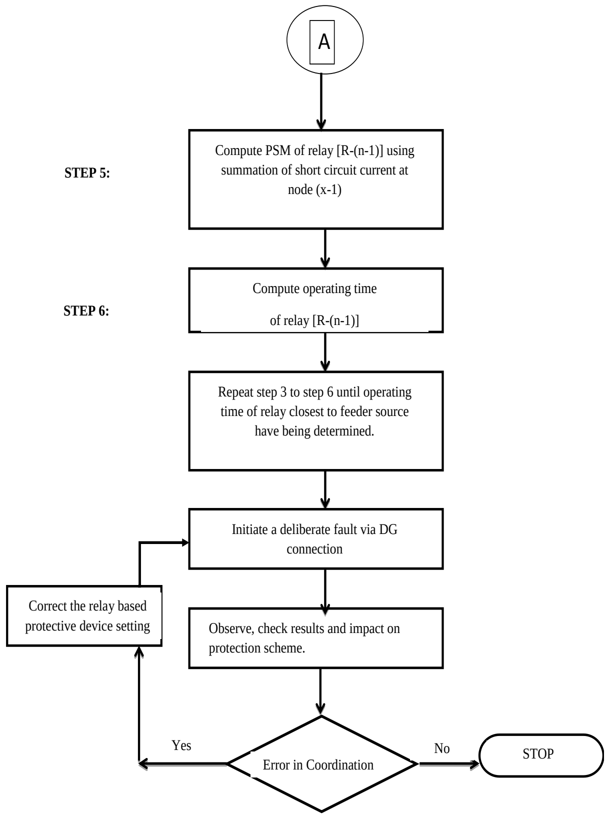


Figure 3: showing Flow chart for determining operating times for protective devices within the selected feeder (Oginigba link road to Ordinance roundabout).

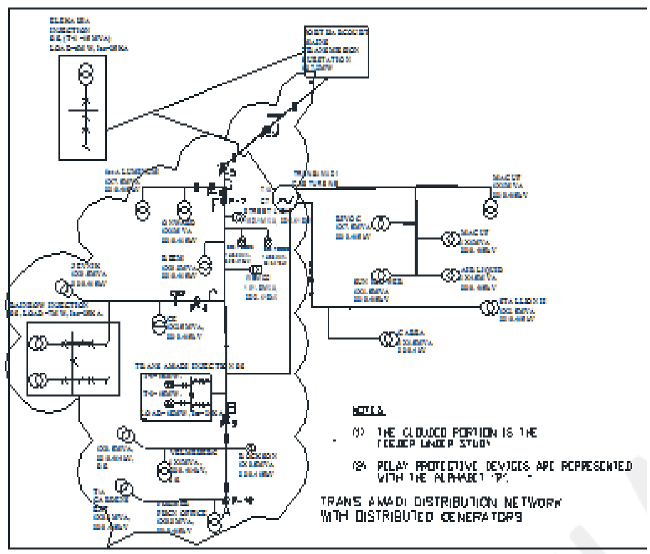


Figure 1: 33 kV Distribution line network with Distributed Generators.

The objective of the design is to determine the impact of generators on distribution lines in relation with the protection scheme. The protective devices employed here are re-closers installed along the main overhead line to interrupt circuit during a temporary fault and closing the circuit after clearing of the temporary fault and sectionalizers are installed at branched overhead

(T-off) lines to interrupt permanent faults along branched overhead lines. The Trans-Amadi Gas turbine is made up of four generators of capacity (4 X 25 MW). The 33 kV network at Trans-Amadi consist of 33 kV lines with hooked up transformers at nodes, is fed from Trans-Amadi power plant made up of 33 kV bus connected to the (4 X 25 MW). The table 1 below shows existing transformers within a network of study, proposed protective devices in relation to their zones of protection and distributed generator parameters.

Simulink blocks (Figure 2) have been used to model equations (1-9) in order to achieve the operating times of protective devices within the network for cases without DG, with DG and with fault current limiter. The following are mathematical expressions to determine relevant parameters for a protection scheme [17].

$$\text{Fault MVA: } MVA = \frac{\text{base MVA}}{Z_{p.u}} \quad (MVA) \tag{1}$$

$$\text{Fault Current: } IF = \frac{\text{Fault MVA} \times (10)^3}{\sqrt{3} \times kV} \quad (A) \tag{2}$$

$$\text{Load Current: } IFL = \frac{KVA \times 1000}{\sqrt{3} \times V} \tag{3}$$

Relay Settings:

$$\text{Time Multiplier Setting} = \frac{OTR * [PSM^{0.02} - 1]}{0.14} \tag{4}$$

$$\text{Plug Setting Multiplier} = \frac{I_{FR}}{I_P} \tag{5}$$

$$\text{Fault current referred to primary of CT} = \frac{I_F}{CT_P} \tag{6}$$

Where CT_p is primary side of current transformer

Total Operating time of Relay (TOTR)

$$= OTR + OTCB + OVTR \tag{7}$$

Where Operating Time of Circuit Breaker (OTCB) = 0.5sec.

Operating time of relay (OTR): top

$$= \frac{0.14 \times TMS}{[PSM^{0.02} - 1]} \quad (\text{Seconds}) \tag{8}$$

$$\text{Overshoot time of relay (OVTR)} = 10\% \times OTR \tag{9}$$

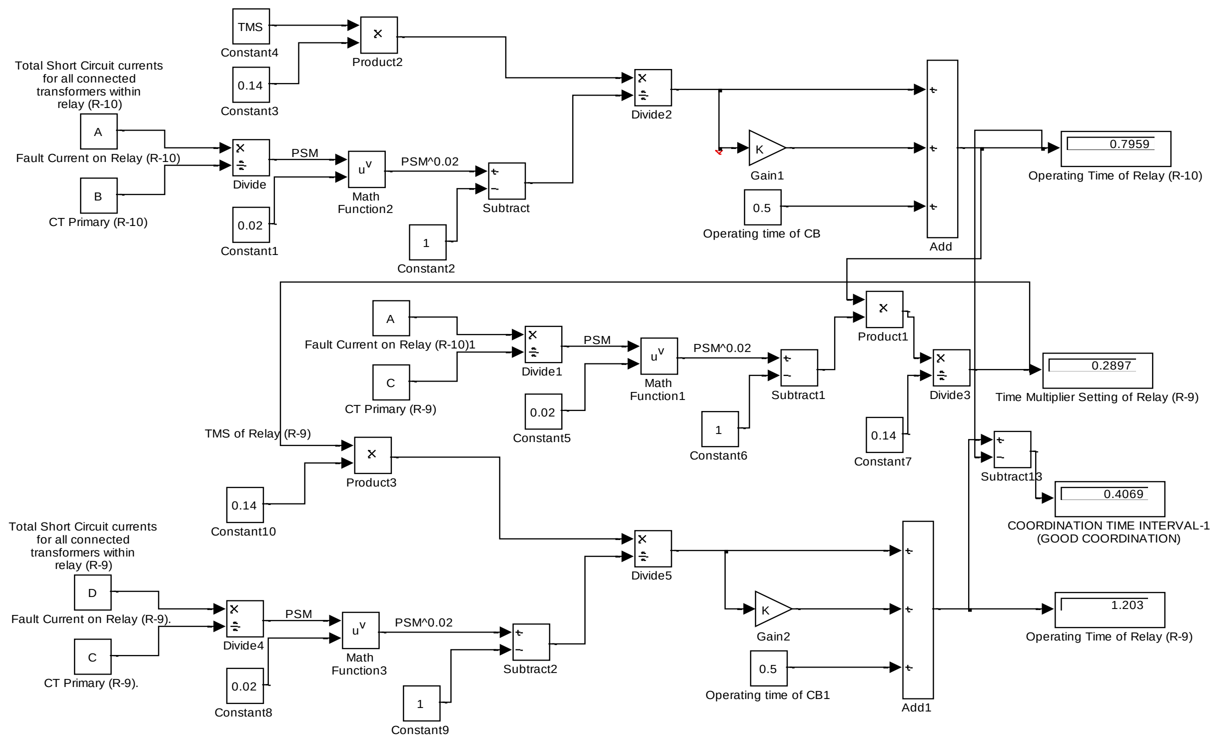


Figure 2: SIMULINK model of relay based protective device operating time.

Table 1: Transformers and generator capacities connected to a 33 kV distribution network from OGINGBA link road to Ordinance roundabout at Trans-amadi, Port Harcourt, Nigeria.

S/No	Zone of protection with protective device	Description	Transformer Capacity
1.	Node A	T/A Gardens distribution station.	1x0.3MVA, Z=4.75% (33/0.415kV)
2.	Node B	V-Hotel Distribution station.	1x2.5MVA,Z=9% (33/0.415kV)
3.	Node C	GPH distribution station.	1x0.3MVA,Z=4.75% (33/0.415kV)
4.	Node D	Rockson distribution station.	1x0.5MVA,Z=4.75% (33/0.415kV)

S/No	Zone of protection with protective device	Description	Transformer Capacity
5.	Node E	GE distribution station.	1x2.5MVA,Z=9% (33/0.415kV)
6.	Node F	Sea Food distribution station	1x0.3MVA, Z=4.75% (33/0.415kV)
7.	Node G	1stAluminum distribution station.	1x1.0MVA, Z=5% (33/0.415kV)

Table 2: Trans Amadi Gas plant installed capacity

S/No	Equipment	Capacity
1.	Generators 1, 2, 3, 4, 5. (Only two utilized)	12MW, 11kV
2.	Circuit Breakers	8kA
3.	Generator Step-up Transformers	25/35MVA, 11/33kV
4.	Station Service Transformer	3MVA, 33/0.415kV

Information relating to the transformer ratings and generator rating are used to perform relay setting operations to determine the operating times of the protective devices for two cases; when the generator is not connected-case1 and when the generator is connected-case2 as shown in Figure 3.

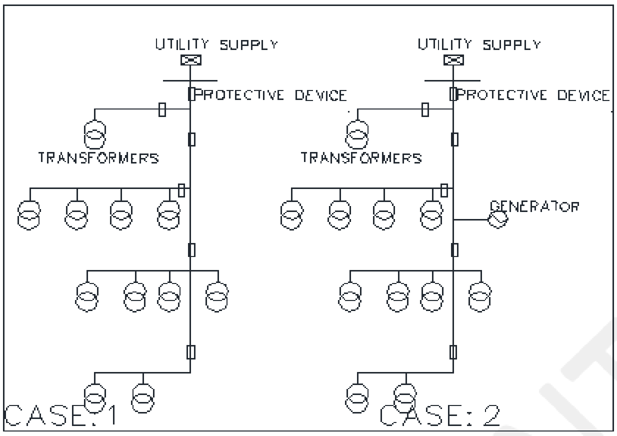


Figure 3: Simplified configuration of a 33 kV Distribution line network without (case 1) and with (case 2) generators.

Compute operating time of protective device for the proposed protection scheme, *without generator (case 1)*. Start relay setting process from downstream or tail end of the selected feeder in the distribution network shown in Figure 1.

Node A – Relay Protective Device (R-10) - Location of T/A Garden Ext and Former PHCN Office Injection substation.

Using equation (1),

Fault MVA for PHCN office & T/A Garden (1x0.3MVA, Z=4.75%),

Fault MVA=0.3/0.0475=6.3157A,

Short circuit current using equation (2),

Fault current== $\frac{6.3157*1000}{\sqrt{3}*33}$=110A

Fault MVA for T/A Garden (1x2.5MVA, Z=9%),

Fault MVA=0.3/0.09=27.78A,

Fault current== $\frac{27.78*1000}{\sqrt{3}*33}$=486A

Total short circuit current at node A = 111A + 486A + 111A = 708A.

Assume a relay protective device (R-10) = 1A, TMS = 1, a selected CT ratio = 56:1 and plug setting = 100% so that PS (pick up) = 1.

From equation (6),

$I_{FR} = \frac{708}{56} = 12.68.$

Using equation (5)

$PSM = \frac{12.68}{1} = 12.68.$

Operating time of relay protective device (R-10), using equation (8)

$t_{op} = \frac{0.14*0.1}{[12.68^{0.02}-1]} = 0.2686sec.$

Determine overshoot of device using equation (9)

OVTR = 0.026896. Assume the operating time of Circuit Breaker = 0.5sec.

Determine total operating time of relay protective devices at Node A

= 0.2686 + 0.5 + 0.02686 = 0.7959sec.

The above is an iterative process and is simulated using Matlab Simulink to obtain operating times for relays protective device (r-8) at node c, (r-6) at node d, (r-5) at node e, (r-4) at node f and (r-3) at node g. Results have been tabulated for cases without dg (Table 2), with dg (Table 3) & with dg and fault current limiter (Table 4). Figure 4 is a simplified Time-Current curve which illustrates coordination time interval (CTI) in Tables 2, 3 & 4 of a relay based protective device.

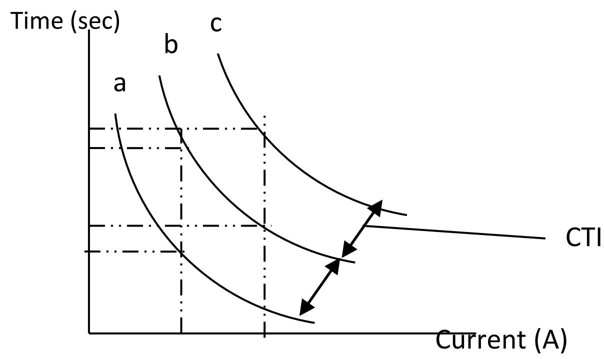


Figure 4: Time Current Curve

The three curves represent protective devices. The CTI is the time interval between main device and back up device. The time current curves for devices a & b (Figure 4) are compared in other to assess their coordination. To determine the operating time to open devices a & b, for a specific overcurrent, vertical line is drawn from current axis to intercept both curves so as to arrive at a maximum time and minimum time respectively.

3. ANALYSIS OF RESULTS

The proposed protection scheme for a distribution network with distributed generators using SIMULINK modeling shows a gradual increase in the operating time of protective devices from most downstream to upstream devices with time lag or delay for succeeding devices (see Table 2).

This above results implies that no two or more protective devices will operate at the same time and devices closest to any fault location will trip making it is easy to identify fault location. When distributed generators are introduced to the proposed scheme (Table 3), there is misbehaviour of protective devices within the point of connection of the distributed generators to the distribution network as the back-up protective device first trips before main protective device for faults closer to the latter. This is due to the fault current contribution from the distributed generators. This malfunctioning of protection scheme is corrected via an automatic controlled fault current limiter (see Table 4).

4. CONCLUSION AND RECOMMENDATIONS

The study has highlighted several literatures relating to protection of distribution network as well as conducted a design for a protection scheme for a distribution network with distributed generators. The Trans Amadi 33 kV radial distribution network although has isolators and circuit breaker installed within network, it is not selectively coordinated and therefore lacks a protection scheme, making it less reliable in continuity of power supply.

Table 2: SIMULINK results of the operating times for protective devices installed in a distributed network without distributed generators.

Node	Relay	Current Transformer Ratio	TMS	Operating Time (Sec) t_n = nth time		Coordination Time (CTI) Interval (t_{n+1}-t_n)	Remark
A	R-10	56:1	0.100	0.796	(t1)	-	
B	R-9	59:1	0.290	1.203	(t2)	0.407	Good Coordination
C	R-8	100:1	0.449	1.779	(t3)	0.576	Good Coordination
D	R-6	100:1	0.687	2.457	(t4)	0.678	Good Coordination
E	R-5	100:1	2.073	2.897	(t5)	0.700	Good Coordination
F	R-4	100:1	2.756	3.678	(t6)	0.781	Good Coordination
G	R-3	100:1	3.508	4.522	(t7)	0.843	Good Coordination

Table 3: SIMULINK results of the operating times for protective devices installed in a distributed network with connected generators.

Node	Relay	Current Transformer Ratio	TMS	Operating Time (Sec) t_n = nth time		Coordination Time (CTI) Interval (t_{n+1}-t_n)	Remark
A	R-10	56:1	0.100	0.796	(t1)	-	
B	R-9	59:1	0.290	1.203	(t2)	0.407	Good Coordination
C	R-8	100:1	0.449	1.779	(t3)	0.576	Good Coordination
D	R-6	100:1	0.687	1.371	(t4)	-0.409	Mis-Coordination
E	R-5	100:1	1.156	1.838	(t5)	0.600	Good Coordination
F	R-4	100:1	1.748	2.521	(t6)	0.684	Good Coordination
G	R-3	100:1	2.405	3.257	(t7)	0.735	Good Coordination

Table 4: SIMULINK results of the operating times for protective devices installed in a distributed network with connected generators through current limiters.

Node	Relay	Current Transformer Ratio	TMS	Operating Time (Sec) t_n = nth time		Coordination Time (CTI) Interval (t_{n+1}-t_n)	Remark
A	R-10	56:1	0.100	0.796	(t1)	-	
B	R-9	59:1	0.290	1.203	(t2)	0.407	Good Coordination
C	R-8	100:1	0.449	1.779	(t3)	0.576	Good Coordination
D	R-6	100:1	0.687	1.804	(t4)	0.023	Good Coordination
E	R-5	100:1	1.522	2.260	(t5)	0.456	Good Coordination

In contrast, the proposed scheme which is selective and coordinated in its protection scheme is more reliable in power supply. Proposed design validates the deteriorating effect that distributed generators can cause on the existing protection scheme of a distribution network as highlighted in the referenced literature of Abdi, *et al* [14] as well as overcoming this technical challenge via fault current limiter. The protection scheme also shows a good coordination of protective devices implying that only upstream devices nearest to fault will trip/open in the event of a short circuit isolating faulted section while the remainder of distribution line is unaffected.

5. ACKNOWLEDGEMENT

We appreciate Port Harcourt Electricity Distribution (PHEDC) and staff of Trans Amadi Power Plant, Port Harcourt, Nigeria for their immense contribution.

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