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Design Of a Protective Scheme for The Distributed Generation System in Rivers State

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Abstract- Due to the increasing demand of energy and the need for nonconventional energy sources, Distributed Generation (DG) has come into play. The trend of unidirectional power flow has been gradually shifting with new technology comes new challenges. The introduction of Distribution Generation (DG) into the conventional power system brings various challenges; one of the major challenges is system protection under Distributed Generation (DG) sources. These sources pose a significant challenge due to bidirectional flows from Distributed Generation (DGs) as well as lower fault current contribution from inverter interfaced distributed generation (DGs). This research work reviews existing protection schemes that have been suggested for active distribution networks. Most of these protection strategies apply only to smaller distribution systems implying that they may need to be extended to larger systems with a much higher penetration of distributed generation. At the end of this research work, a potential protection scheme has also been recommended as a future work based on the improvement in technology.

Indexed Terms- Design, Protective, Scheme Generation, Time-current

I. INTRODUCTION

An electric power system is a network of electrical components deployed to supply, transfer, and use electric power. An example of an electric power system is that it provides power to an extended area. 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, (Javadian, *et al.*, 2013). 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)

DG requires use of large small size distributed generators within the radial network (Mesut, *et al.*, 2004). DG can be categorized into direct current (D.C) power generators or alternating current (A.C) power generators and distributed generator referred to in this study is the Trans Amadi gas fired alternating current generator.

These distributed generators hen 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 (Paul *et al.*, 2015). 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 (Xinjia *et al.*, 2008). Change in power flow impacts on the network in the following areas; reliability, operation, protection and control of existing power source and islanding operations (Chowdhury *et al.*, 2009). 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. 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 (Helen *et al.*, 2009).

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, 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 (Kamel, 2013). 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. 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 (Onkol, 2011).

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 (Sung *et al.*, 2010). 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.

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 the operation while at the same time operate as fast as possible within the main/primary zone of protection. This is possible using the technique of inverse time overcurrent relays which function in such a way that as the operating time increases, the current magnitude decreases. The whole essence of selectivity or coordination is to ensure maximum power delivery with minimum power system disconnection (Abdi, *et al.*, 2011).

II. STATEMENT OF THE PROBLEM

Power grids have gathered a significant amount of attention within the past decade and becoming an essential asset in the energy industry. The ability to integrate sustainable energy generation methods into the distribution network is one of the main reasons for microgrids popularity. A wide variety of Distributed Generation (DG) including wind and other micro-turbine generation, photovoltaic generation along with energy storage, make the microgrid viable in both grid-connected and islanded modes while reducing the power losses. There are various technical challenges to be tackled in order to harvest the full potential of microgrids, and protection is one of them. When a distributed generator is not protected failure will become inevitable. Various solutions were introduced, driven by the development of protection techniques which is known as protection scheme.

III. AIM AND OBJECTIVES OF THE STUDY

The aim of this study is to design a protective scheme for the distributed generation system in Rivers State. The specific objectives of this study are to:

i Study the design and protection scheme which provides an understanding of protective device coordination that involves the choosing of protective relay for devices.

ii Determine the time-current setting within the feeder length in order to isolate equipment and feeders from faults.

iii Design a protection scheme that will be more extensible to allow additions of future distribution generated (DGs) with little or no modifications to the existing scheme.

iv Design a scheme which will provide security to the distributed generation and to ensures that the main protective device operate quickly in the event of a fault.

MATERIALS AND METHOD

- Simulation Software

ETAP (Electrical transient analysis program) was be used in designing and simulating the Trans-Amadi 33KV network.

- Network Block Diagram

Figure 3.1 shows the block diagram of Trans-Amadi 33KV distribution network where power is distributed to the various units stated in the figure.

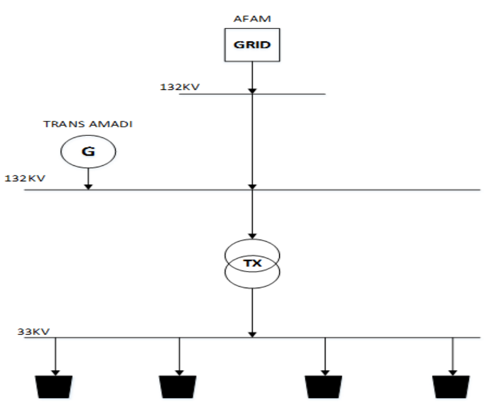


Fig. 3.1: Network Block Diagram Trans-Amadi 33KV Network

The above diagram shows the Trans-Amadi 33kv network block diagram, the network is made of the grid IPP Afam supplying the bus bar b1 while the trans-Amadi generation plant supplies to b2 all supplying transformer TX1 stepping the voltage to the 33KV Trans-Amadi network.

- Network Properties

Table 3.1 shows the major elements of the network and their power ratting

Table 3.1: Network Properties of the Trans-Amadi 33KV Network

S/N	Element	ID	Ratting (MW)
1	Grid	Afam IPP	
2	Generator	Trans-Amadi	30mw
3	Transformer	T1	60MW
4	Loads	RSPUB 1	8.2MVA
		ABULOMA	8.5 MVA
		UNIPORT	17.6 MVA
		REF 1	1.8 MA

- Network Simulation

The network simulation was used carried out in 3 stages listed below in the order of preference.

i. Designing the network ETAP edit environment.

ii. Running a power flow simulation of the network

iii. Running the protection scheme selected from chapter 1 (Bus Bar differential)

3.2.4 Network Assembling in ETAP

First the network has to be laid out in the ETAP editing environment, in the editing environment, all network elements, the grid, TX, Gen would be assembled together to form the proposed network with their properties parameters one after the other.

3.3 Power Grid Placement

Figure 3.2 shows the power grid ETAS editor page showing all the short circuit parameters/ratings

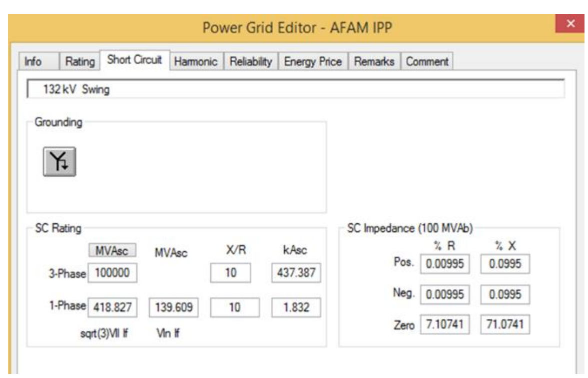


Fig. 3.2: Power Grid of ETAP editor page

- Synchronous Generator Placement

The synchronous generator parameters are shown in figure 3.3, showing which are ratting in both Mega Watts as well as Mega Volt Ampere as well as the connected BUS voltage, the full load amperes, the generator number of poles. While on the down side of the figure, the prime mover generator settings are shown as well as generator operating values.

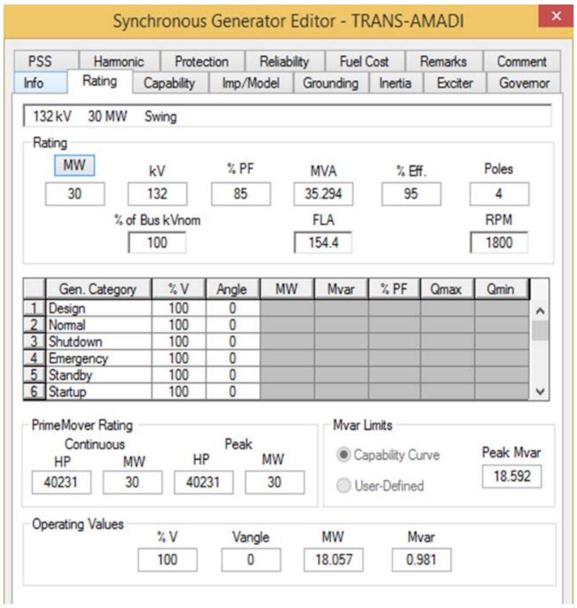


Fig. 3.3: Synchronous Generator

- Winding Transformer Placement

The below figure shows the ratting for the step-down winding transformer, a two-winding transformer with a primary input of 132va and of 33kva, an FLA of 262.4 and 1050 FLA for the primary and secondary voltage respectively as well as a 60 Megawatts transformer ratting

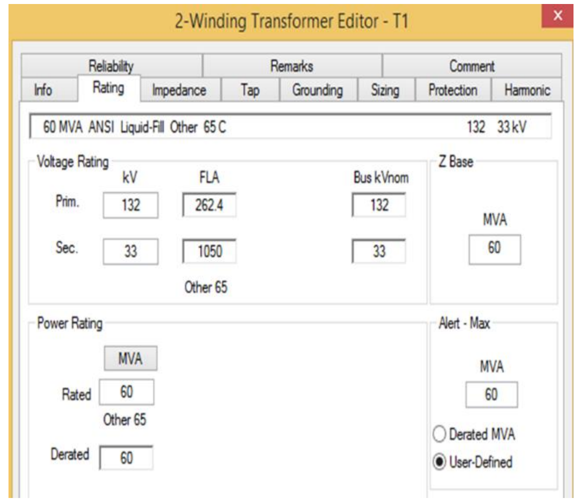


Fig. 3.4: Winding Transformer

- Network in Edit Mode

The below figure shows the entire network in edit mode ready to be assembled for power flow simulation after proper network element parameters have been entered

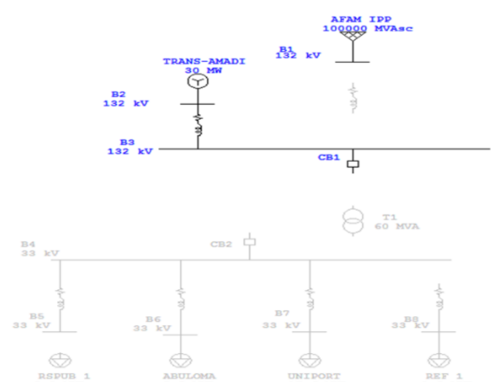


Fig. 3.5: Network in Edit

- Network in Power Flow Simulation Mode

The below figure shows the assembled network in power flow mode, the analysis will be done in next chapter.

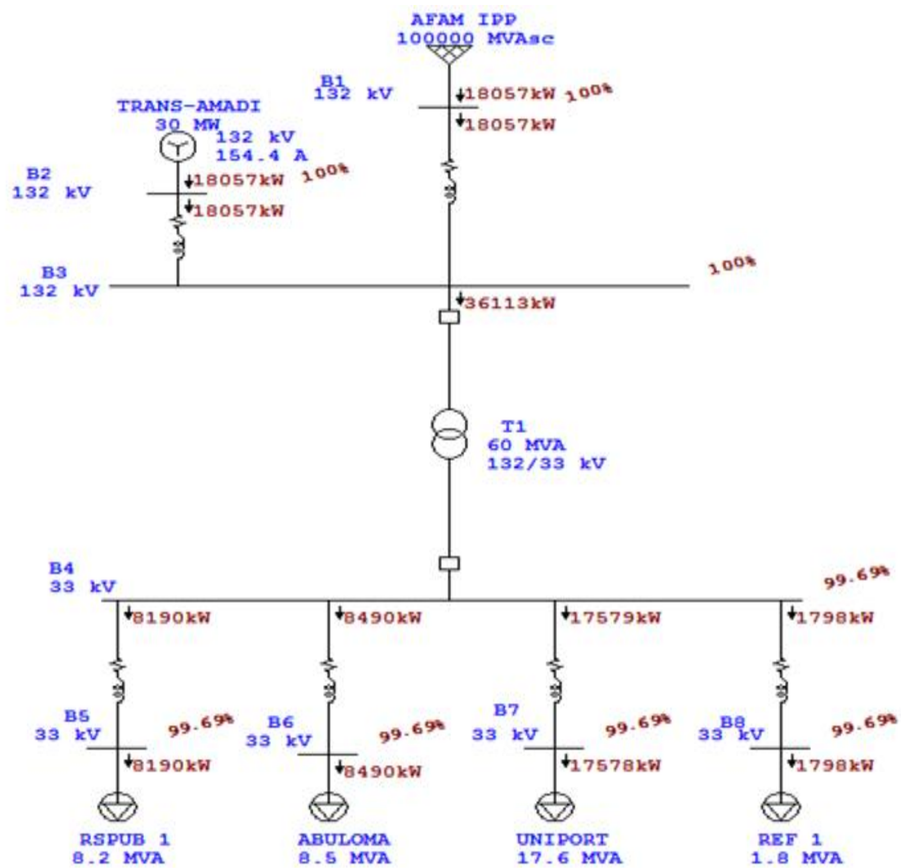


Fig. 3.6: Network in Power Flow Simulation Mode

Network 33KVA Bus Bar Differential Protection Scheme

- Current Transformer Settings

a) Incoming current transformer
b) outgoing current transformer
c) Incoming current transformer
d) The ratio for the outgoing current transformer is 1000:1 in amperes with a burden of 10-volt ampere. While
e) The ratio for the outgoing current transformer is 100:1 in amperes with a burden of 10-volt ampere.

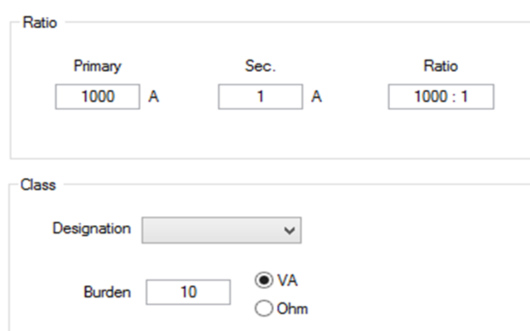


Fig. 3.7: Incoming Current Transformer

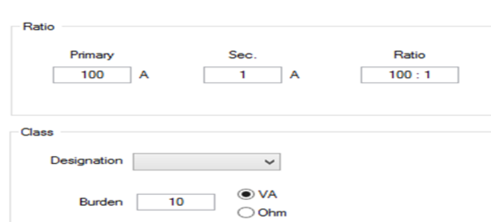


Fig. 3.8: Outgoing Current Transformer

- Differential Relay Library Pick

The below figure shows the differential relay data sheet

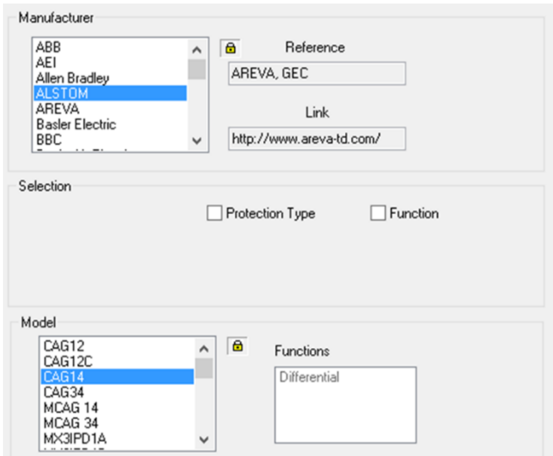


Fig. 3.9: Differential Relay Library Pick

- Differential Relay Input

The figure below shows the deferential relay inputs numbering CT1 -CT5, they are the incoming and outgoing current transformers.

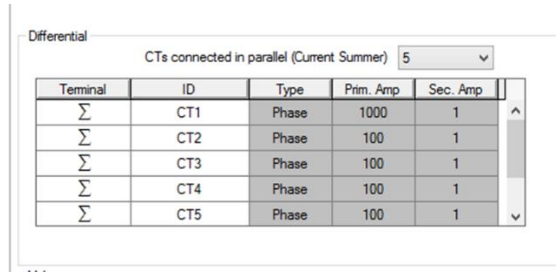


Fig. 3.10: Differential Relay Input

- Differential Relay Output Interlock

The below figure is showing the relays output interlock.

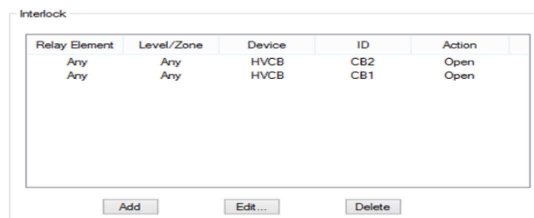
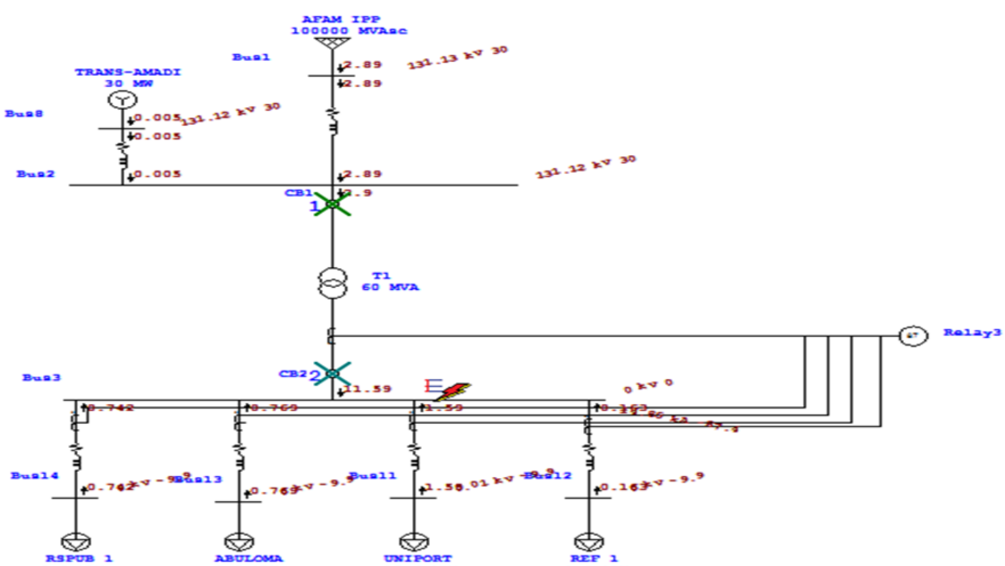


Fig. 3.11: Differential Relay Output Interlock

- Network in Bus Bar Differential Simulation Mode

The network in bus bar differential simulation, showing how the breakers trips and saving the network form collapse once there is a fault along the 33kva bus. The simulation result will be analyzed in the next chapter.



IV. RESULTS AND DISCUSSION

- Power flow Result Presentation

    - Power Flow Elements Performance Table

Below is a summarized table of the performance of the network elements based on the performance, these data will now be used to analyses the network in power flow mode.

Table 4.1: Power Flow in kW Mode Power Flow Elements Performance

S/N	Network Element	Bus Voltage in Percentage (%)
1	Bus B1	100
2	Bus B2	100
3	Bus B3	100
4	Bus B4	99.69
5	Bus B5	99.69
6	Bus B6	99.69
7	Bus B7	99.69
8	Bus B8	99.69
	Network Element	Transformer
9	Tx	132/33
	Network Element	Load
10	Rspub1	8.2MVA
11	Abuloma	8.5MVA
12	Uniport	17.6MVA
13	Ref 1	1.8MVA
	Network Element	Load
14	Generator	30MVA

Bus Voltage Performance in Percentage

- Network Power Flow in Bus % Voltage Mode

The Figure below shows the network with all Bus performance in percentages.

- 1Power Flow Analysis

Referring to the table of data above it is clearly shown that the network performance during power flow is very healthy with no critical or marginal buses or probably over voltage or under voltage bus. With this the network can now be further analysed in the bus bar differential scheme mode having passed this stage with an A score.

- The Bus Bar Differential Scheme Presentation

The figure below shows the network during bus bar differential simulation. Once there is a problem on the 33kva BUS the differential relay sequence of operation to make sure the 33kva does not fail or brake in shown below:

The circuit breaker CB1 open immediately in milliseconds seconds based on the time setting in the differential relay.

- Sequence of Operation

The below graph shows the operation sequence of the relay being tripped in mille seconds in the occurrence of a fault on the bus it is as well represented on the below graph.

On the occurrence of a faulty bus the differential sets into operation at 20 mill seconds and trips of the CB1 83.3 ms and also CB2 at 83.3 ms.

Table 4.2: Sequence of Operation

S/N	ID	Time (MS)	Condition
1	Diff relay	20.0	Phase 87
2	CB1	83.3	Tripped by diff relay Phase 87
3	CB1	83.3	Tripped by diff relay Phase 87

- Wind Turbine Parameters

This table provides the parameters used in the wind generator model within PSS/E to represent the power output from the wind turbine. These parameters were changed to represent a change in the number of wind turbines connected to the busbar in the model. The remaining parameters not shown here were used to describe the connections of the wind generator model to the busbar. These parameters include the base value, the resistive and reactive transient values, which were represented by the PSS/E default values. The resistance and reactance of the generator is represented within PSS/E as the Parameter - Zsource. The stator resistance and reactance in the table below represent Zsource.

Table 4.3: Parameters for the Connection of Wind Turbines at Busbar 5,6,7,8,9&10

No. of Turbines	Power Real	Reactive	Stator Resistive	Reactive
	MW	MWArs	p.u.	
1	2.3	1.209	0.0063	0.1605
2	4.6	2.418	0.0126	0.321
3	6.9	3.627	0.0189	0.4815
4	11.5	6.045	0.0315	0.8025

Table 4.4: Wind Turbine Connection Diagram

No. Of Turbines	Power		Stator	
	Real MW	Reactive MVArs	Resistance p.u.	Reactive
1	2.3	1.209	0.0063	0.1605
2	4.6	2.418	0.0126	0.321
3	6.9	3.627	0.0189	0.4815
5	11.5	6.045	0.0315	0.8025

Table 4.5: Parameters for the Connection of Wind Turbines at Busbar 5, 6, 7, 8, 9 & 10

Connection at Busbar 7	Connection at Busbar 6	Connection at Busbar 5
Busbar 5	Busbar 5	Busbar 5
Busbar 6	Busbar 6	Busbar 6
Busbar 7	Busbar 7	Busbar 7
Busbar 8	Busbar 8	Busbar 8
Busbar 9	Busbar 9	Busbar 9
Busbar 10	Busbar 10	Busbar 10

Connection at Busbar 10	Connection at Busbar 9	Connection at Busbar 8
Busbar 5	Busbar 5	Busbar 5
Busbar 6	Busbar 6	Busbar 6
Busbar 7	Busbar 7	Busbar 7
Busbar 8	Busbar 8	Busbar 8
Busbar 9	Busbar 9	Busbar 9
Busbar 10	Busbar 10	Busbar 10

Table 4.6: Fault Level Results with Wind Generation connection at Busbar 10

1 Turbine Connected to Busbar 10, Fault on Feeder 10

Relay	10	9	8	7	6	5
Fault Level (A)	9468 a+b	1712a	1712a	1767a	1958 a	1958a
Trip Time (S)	**	0.62	0.983	1.439	2.016	2.8

1 Turbine connected to busbar 10, fault on feeder 9

Relay	10	9	8	7	6	5
Fault Level (A)	-	2022a	2031a	2057a	2217a	2217a
Trip Time (S)	-	0.58	0.917	1.325	1.854	2.558

1 Turbine connected to busbar 10, fault on feeder 8

Relay	10	9	8	7	6	5
Fault Level (A)	-	3518b	2361a	2374a	2497a	2497a
Trip Time (S)	-	0.516	0.863	1.233	1.725	2.369

1 Turbine connected to busbar 10, fault on feeder 7

Relay	10	9	8	7	6	5
Fault Level (A)	-	2923b	2904b	2681a	2769a	2769a
Trip Time (S)	-	0.518	0.799	1.16	1.624	2.222

1 Turbine connected to busbar 10, fault on feeder 6

Relay	10	9	8	7	6	5
Fault Level (A)	-	2284b	2259b	2239b	3383a	3383a
Trip Time (S)	-	0.554	0.879	1.268	1.461	1.987

1 Turbine connected to busbar 10, fault on feeder 5

Relay	10	9	8	7	6	5
Fault Level (A)	-	1894b	1865b	1839b	1806b	4235a+b
Trip Time (S)	-	0.594	0.951	1.407	2.133	1.776

Table 4.7: Fault Level Results with Wind Generation connection at Busbar 8

1 Turbine connected to busbar 8, fault on feeder 9

Relay	10	9	8	7	6	5
Fault Level (A)	-	6054a +b	6080a+ b	1529a	1773a	1773a
Trip Time (S)	-	**	0.738	1.564	2.16	3.016

1 Turbine connected to busbar 8, fault on feeder 8

Relay	10	9	8	7	6	5
Fault Level (A)	-	-	10481a +b	2470a	2602a	2602a
Trip Time (S)	-	-	**	1.21	1.683	2.308

1 Turbine connected to busbar 8, fault on feeder 7

Relay	10	9	8	7	6	5
Fault Level (A)	-	-	5816b	2788a	2882a	2882a
Trip Time (S)	-	-	0.74	1.144	1.591	

1 Turbine connected to busbar 8, fault on feeder 6

Relay	10	9	8	7	6	5
Fault Level (A)	-	-	-	3685b	3515a	3515a
Trip Time (S)	-	-	-	1.017	1.434	

1 Turbine connected to busbar 8, fault on feeder 5

Relay	10	9	8	7	6	5
Fault Level (A)	-	-	-	2707b	2656b	4391a
Trip Time (S)	-	-	-	0.811	1.159	1.664

Table 4.8: Fault Level Results with Wind Generation connection at Busbar 7

1 Turbine connected to busbar 7, fault on feeder 9

Relay	10	9	8	7	6	5
Fault Level (A)	-	4530a +b	4551a+ b	4615a+ b	1544a	1544a
Trip Time (S)	-	0.515	0.739	0.933	2.412	3.399

1 Turbine connected to busbar 7, fault on feeder 8

Relay	10	9	8	7	6	5
Fault Level (A)	-	-	6969a+ b	7011a+ b	2042	2042a
Trip Time (S)	-	-	0.739	0.852	1.958	2.715

1 Turbine connected to busbar 7, fault on feeder 7

Relay	10	9	8	7	6	5
Fault Level (A)	-	-	-	10817a +b	2831a	2831a
Trip Time (S)	-	-	-	**	1.602	2.195

1 Turbine connected to busbar 7, fault on feeder 6

Relay	10	9	8	7	6	5
Fault Level (A)	-	-	-	-	3455a	3455a
Trip Time (S)	-	-	-	-	1.446	1.965

1 Turbine connected to busbar 7, fault on feeder 5

Relay	10	9	8	7	6	5
Fault Level (A)	-	-	-	-	3214b	4321a
Trip Time (S)	-	-	-	-	1.499	1.759

Table 4.9: Fault Level Results with Wind Generation connection at Busbar 6

1 Turbine connected to busbar 6 , fault on feeder 9

Relay	10	9	8	7	6	5
Fault Level (A)	-	3190a+ b	3206a+ b	3251a+ b	3531	1475
Trip Time (S)	-	0.516	0.771	1.071	1.43	3.54

1 Turbine connected to busbar 6, fault on feeder 8

Relay	10	9	8	7	6	5
Fault Level (A)	-	-	4306a+ b	4333a+ b	4583a+ b	1732
Trip Time (S)	-	-	0.741	0.956	1.268	3.074

1 Turbine connected to busbar 6 , fault on feeder 7

Relay	10	9	8	7	6	5
Fault Level (A)	-	-	-	5767	5975	2080
Trip Time (S)	-	-	-	0.862	1.133	2.68

1 Turbine connected to busbar 6 , fault on feeder 6

Relay	10	9	8	7	6	5
Fault Level (A)	-	-	-	-	115943492	
Trip Time (S)	-	-	-	-	0.963	1.956

1 Turbine connected to busbar 6 , fault on feeder 5

Relay	10	9	8	7	6	5
Fault Level (A)	-	-	-	-	-	4365a
Trip Time (S)	-	-	-	-	-	1.748

Table 4.10: Fault Level Results with Wind Generation connection at Busbar 5

1 Turbine connected to busbar 5, fault on feeder 9

Relay	10	9	8	7	6	5
Fault Level (A)	-	2475a +b	2488a +b	2526a +b	2754a +b	2755a +b
Trip Time (S)	-	0.54	0.847	1.197	1.6	2.224

1 Turbine connected to busbar 5, fault on feeder 8

Relay	10	9	8	7	6	5
Fault Level (A)	-	-	3128a +b	3149a +b	3340 a+b	3341
Trip Time (S)	-	-	0.778	1.085	1.47	2.204

1 Turbine connected to busbar 5, fault on feeder 7

Relay	10	9	8	7	6	5
Fault Level (A)	-	-	-	3875a +b	4022 a+b	4023a+ b
Trip Time (S)	-	-	-	0.998	1.345	1.821

1 Turbine connected to busbar 5, fault on feeder 6

Relay	10	9	8	7	6	5
Fault Level (A)	-	-	-	-	6242	6242
Trip Time (S)	-	-	-	-	1.115	1.5

1 Turbine connected to busbar 5, fault on feeder 5

Relay	10	9	8	7	6	5
Fault Level (A)	-	-	-	-	-	12593
Trip Time (S)	-	-	-	-	-	1.242

V. OBSERVATIONS FROM FAULT ANALYSIS

- Connections at Busbar 10

Connection of distributed generation at the bottom of the network increases the load flow and fault level flowing through this busbar and feeder. Generally, the current transformer for the feeder relay would be required to be increased to match the new loadflow. The load flow results for distributed generation connection at busbar 10 show similar load flow through busbar 9 and 10, this could make providing new settings for relay 10 difficult as the current setting for both relays would be similar. For a fault on feeder 10, the remaining 11kV feeders will see fault contribution from the main generation source only and because of the impedance down the network these fault levels are much smaller than the fault level on feeder 10.

For a fault on feeder 8 the fault level seen by the relay on feeder 9 is higher than the fault level on feeder 8. The fault level through the current transformers to the fault on feeder 8 is from the main generation source whereas the fault level through the current transformers on feeder 9 is from the wind -power source. In this case the relay at feeder 9 operates at 0.516s and trips the associated circuit breaker before feeder 8 operates, feeder 8 will operate at 0.863s resulting in loss of supply to busbar 9 and busbar 8. This will result in the power being cut off to loads downstream of the fault; this is the same as what would be expected in a traditional radial network.

- Connection of Wind Generation higher up the 11kV distribution network

With the connection of the wind -turbines moving up the network more changes are required to the feeder protection on the 11kV network. This is due to higher load flow from the combined generation sources. The fault levels on the 11kV network will increase. The most dramatic increase of fault level is closest to the wind-turbine connection. As the connection of generation moves up the network the fault levels are more consistent. In general, the operation times of the relays with regard to grading margin seem to have improved with the connection of distributed generation.

The contribution from the wind-turbines can be of a transient nature therefore the network could operate over periods where the network flow is passive and not active. This could affect the operation of the relay when the settings have been modified as the operation fault level that the new settings were based on may never be achieved under passive operation

- Setting Principles of KCEG142

The directional relay proposed for the use on a radial network with distributed generation is a RSU. This is a protection relay manufactured by Area Transmission and Distribution. This relay is a digital multifunction relay, based on an induction disc principle but with a digital processor and liquid crystal display. The relay is capable of measuring overcurrent and earth fault, directional overcurrent, and earth fault, under frequency and under voltage and thermal overload and has L.E.D. indication for a trip condition or fault condition.

The elements of the relay that must be set for fault injection by secondary injection are the system data, phase fault protection group 1, and relay mask. The system data element contains information on the relay serial number, type of communication that the relay will use when communicating remotely, software within the relay, frequency that the relay will operate at. Within the phase fault protection group 1 element the overcurrent settings and directional overcurrent settings can be set. There is a two-stage overcurrent function that can be set with time delay and curve type available and a 3-stage directional overcurrent element with time delay. The characteristic angle for the directional element is also set within the phase fault element The under voltage relay settings can also be set within this element. Once the settings have been entered into the relay via the menu the output relays can be set. The output relays are set within the relay masks element. The relay masks element is a list of functions that can make the output relays operate. The relay masks are using logic ‘1’ high ‘on’, ‘0’ low ‘off’ the functions, once set within the relay govern what condition will make the relay trip or alarm. For an output trip on directional current I>Rev and CB>trip would be set high.

Placement of Directional Relays on Radial Network

There are two possibilities discussed here for using directional relays on the radial network. The first possibility is to connect the directional relay at the top of the distributed generation feeder before connecting to the radial network bus bar. The relay would be required to operate on an instantaneously on reverse direction only for a fault condition. This would disconnect the distributed generation from the radial network. This would result in a fault on the radial network being fed from the main source of generation connected to Busbar 1; minimal change would be required within the 11kV radial network as the fault levels would be similar to a network without distributed generation. The overcurrent settings would have to be checked to ensure that account was taken of the increased load flow provided by the distributed generation, to ensure an overload trip did not occur. The problem with this method is that all of the loads on the network will be tripped off; as both sources of supply will be lost (this is assuming the fault is on the 11kV network and not on the distributed generation feeders).

The second method is to place directional relays on feeders 9, 8, 7 and 6 and at the closest position to the 11kV connection on the distributed generation feeder. The relays will be placed next to the overcurrent relays but the relays will only operate on reverse fault flow. The relays will have operational settings such that the directional relay at 6 will have an instantaneous trip setting and the time multiplier setting will increase as the relay position moves closer to Busbar 10. The directional relay on the distributed generation feeder will have the largest time multiplier setting.

- 11kV feeder Network with Directional Relay

Consider a fault on feeder 5 with distributed generation connected to Busbar 10. For a fault at feeder 5 the directional relay at relay 6 should operate first, this would cease fault flow up the radial network. The fault level flowing through the overcurrent relay at 5 would increase as the impedance of the whole network has decreased due to the operation of relay 6. The overcurrent relay at relay 5 would then operate and clear the fault. This is known as cascade tripping. Using this technique, the loads in the 11kV network would still be operating on the radial network.

As the fault moves down the network the relay above the fault would operate on overcurrent protection and the relay below the fault would operate on a directional setting. For a fault occurring on feeder 9 the overcurrent relay at 9 would operate first with the directional relay on the distributed generation feeder providing back up to remove the distributed generation. For a fault at feeder 10, the fault flow would be the combined flow from the main generation source connected to Busbar 1 and the flow from the distributed generation. Therefore, a directional overcurrent relay is not required on this feeder.

- Distributed Generation Connected Higher up the Radial Network

When the distributed generation connection is placed higher up in the radial network less directional relays are required. A fault that occurs further down the network will have fault flow from only one direction and can therefore be cleared by the overcurrent relay. A fault that occurs higher up the network than where the distributed generation is connected shall require the use of directional relays as well as overcurrent relays to clear the feeder with minimal interruption. This would operate in a similar manner to that already discussed in the last paragraph.

- Fault on Feeder 9 with Distributed Generation Connected to Busbar

Section 2 has looked at the use of a directional overcurrent relay to operate for abnormal conditions such as faults when distributed generation has been connected to a radial distribution network. The use of directional relays has been provided as an alternative to differential protection as the communication medium between the differential relays can be expensive to retrofit on an existing distribution network. This section has looked at the setting criteria required to operate the relay.

The conclusions from section 2 are that directional relays can be used in conjunction with the existing overcurrent protection on the network to operate and clear a fault causing minimal disruption to the radial network. This can be achieved by placing directional relays on each feeder that is higher up the network than the distributed generation. The distributed generation feeder will also have a directional relay placed at the closest point to the busbar connection on the radial network. The directional relays will be set using a time-delayed characteristic, which only operates for a reverse current flow up the network. The characteristic angle within the directional relay will be set for a fault taking into consideration any transformers in the current path where a phase shift has been employed. The directional relay highest up the network will be set with the shortest time and so on down the radial network, with the directional relay on the distribution feeder being set with the longest time. All relays further down the network than the distributed generation will only require an overcurrent relay as a fault that occurs on one of these feeders will have fault current flow from one direction only. This will include the feeder relay whose cable is attached to the same busbar as the distributed generate

CONCLUSION

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. 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.

RECOMMENDATIONS

This project is written to modify and anticipate the further protective means on our distribution system to ensure good protective measures and to avoid future breakdown. It is also recommended that protective schemes be designed and implemented in all systems for reliability purposes. Again, the use of protective devices such as circuit breaker, relays etc. should also be encouraged for the overall efficiency of the system.

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