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Distributed Generation and its Impact on Power Micro-Grid Protection (Case Study: SPDC Forcados)

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ABSTRACT
Synchronous DGs contribute significantly to fault current and thus have a great amount of effect on the operation of the protection system (in this case micro grid protection system). Presently, the space between the supply and demand of electricity has been looked into, using distribution generator (DG) technology to bridge the gap. When this technology is appropriately placed in the power network, there is always amelioration in power loss reduction, voltage profile, and system reliability. Thus this study presents a FORCADOS SPDC network, which utilizes the introduction of DGs into the network. The model minimizes voltage deviation and power loss while maximizing voltage stability factor and efficiency. It is seen that after the DGs are introduced into the FORCADOS network, the fault MVA reduces drastically. Microgrid protection system poses a challenge as fault current level increases in electrical power systems due to the introduction of Distributed Generations (DGs) and an increase in network interconnections. NEPSI, and ETAP software were major tools used to achieve optimal protection coordination with DGs. The ETAP simulation with and without the introduction of DGs in the power network was analyzed to obtain the short circuit current and fault MVA values. It is seen that the introduction of DGs into the micro grid or into an already existing power network disrupts its protection scheme but enhances power loss minimization.

KEYWORDS: *Distributed generation, Load Flow Analysis, Short-Circuit Current Analysis, Relay Coordination.*

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I. INTRODUCTION

Microgrids are modern, localized, small-scale grids [1], [2]. They are typically low-voltage AC grids; and employ different distributed energy resources. They could be Off-grid or Independent Micro-grids which are not connected to the Main or Utility grid; Campus or Customer Micro-grids, which are connected to the local grid; and Community or Utility Micro-grids, which are connected to the main grid serving a lot of people within the community [3].

Distributed generation is the integrated or stand-alone use of small, modular electricity generation resources by utilities, utility customers, and/or third parties in applications that benefit the electric system, specific end-user customers, or both. Co-generation and combined heat power (CHP) are included [4]. From a practical perspective, it is a facility for the generation of electricity that may be located at or near end users within an industrial area, a commercial building, or a community [5].

The number of distributed generations (DGs) such as solar power, wind power, microgrids, DC systems, and power electronics devices has risen together with population and industrial energy demand, making system safety and control complicated [6], [7]. However, demand for electrical energy may be forecast or projected using an autoregressive approach [8], [9] but this may not be sufficient for the protection scheme as power demand increases. DGs and interconnectivity increase hence, the fault current level also increases significantly and disrupts the protection coordination [10]. Over the years, a major drawback in the electrical industry especially in radial electrical power system networks has been the loss of continuity due to a fault occurring on the swing bus bar thereby sending a trip command to the breakers associated with the generators. In electrical power systems, faults are inevitable and therefore schemes must be put in place in order to minimize the effect of the fault while it is being cleared as soon as possible [11].

Major drawbacks due to the introduction of DGs in an already existing network could be its technical, economic, and regulatory effects. It increases the values of short-circuit currents in the network, changes the coordination of the system and thus poses as a threat, therefore the need for re-coordination [12]. Distributed generation scheme is the aspect of ensuring adequate reliability, selectivity, and sensitivity of protective devices, especially relay. Increased fault current levels as a result of DGs and interconnectivity in an existing distribution system may necessitate a whole system overhaul, which can be difficult and costly. Abnormal conditions such as magnetizing the inrush current of transformers and starting current of an induction motor may lead to an incessant tripping sequence of protective relays if not properly coordinated due to voltage instability in the power system. In this scheme, it is quite difficult for the relay (if not properly configured) to distinguish between normal, abnormal and fault conditions of the power system network due to the fact that the power generation topology is an interconnected power system thereby massively enhancing the difficulty in maintaining stability.

1.1 The Aim of This Research Work
The goal is to evaluate the impact of distributed generation on power micro grids protection.

1.2 Objective of this Research Work
- Study load flow of Forcados power distribution network using ETAP.
- Determine full load current (FLA) of associated devices in the distribution system.
- Study the existing coordination system.
- Propose solution to the improvement and protection of the power micro grid.
- Look at the impact of DGs on a power micro grid.

II. MATERIALS AND METHOD

2.1 Materials
The materials used for this research work are: Single Line Diagram (SLD) and IEC (International Electro-Technical Commission), and data obtained such as % impedance or per unit impedance values obtained from the field; data obtained in practical analysis of sectional buses; typical practical data obtained from DGs, and existing relays setting obtained from the FORCADOS power network. NEPSI Software, AutoCAD 2018 andETAP 19.0.1C were software also used for design, simulation and coordination.

2.2 Single Line Diagram of FORCADOS Power Station
The Single line diagram shows the main connections and arrangements of the system components. It is made up of six numbers of 11.25MVA synchronized alternators, supplying to the 11KV bus bar, which in turn supplies to two 25MVA 11/33KV power transformers. These step up the voltage level, thereby supplying to the 33KV bus bar on which the transmission lines are connected, it then supplies to the next 33KV bus bar, which feeds two 12MVA and two 6.5MVA loads as shown in Figure 1.

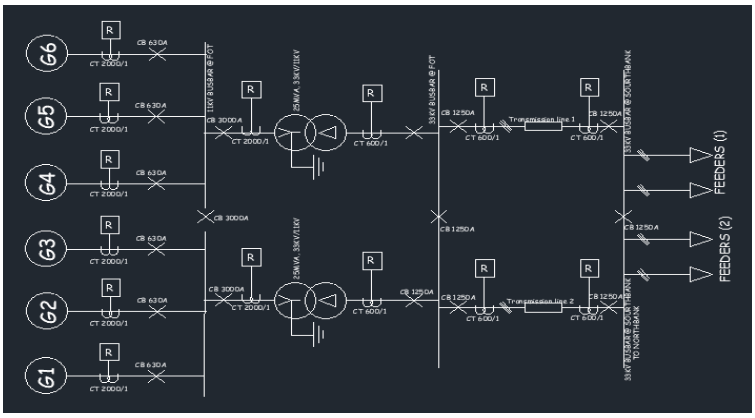

Figure 1: AutoCAD Presentation of the Single Line Diagram of SPDC FORCADOS Network

2.3 Existing Load Flow and Fault Analysis of FORCADOS Power Station Using the Application of Impedance Method and Short Circuit Capacity.
From the analysis of fault calculations as shown below, using the P.U impedance method, which enables the formation of impedance/reactance diagram in the single line diagram (SLD), the selection of system components such as CB, was resolved. The SPDC Forcados power network was zoned into sections for easy and faster analysis. It is seen that the per unit impedance is calculated with (1), while the per unit impedance referred

to both old and new are evaluated in (2) and (3). The new and the old impedance were both equated in (4). The relationship between old and new MVA and Z_{pu} are shown in (5). The short circuit capacity and full load current are determined in (6) and (7). Fault MVA and fault current are gotten using (8) and (9).

$$Z_{p.u} = \frac{Z}{Z_b} = \frac{Z}{\frac{(KV_b)^2}{(MVA)_b}} = \frac{Z(MVA)_b}{(KV_b)^2} \quad (1)$$

From the system, carrying out base conversion analysis is as follows;

$$[Z_{p.u}]_o = \frac{Z\,(MVA)_o}{(KV)_0^2} \quad and \quad (2)$$

$$[Z_{p.u}]_n = \frac{Z(MVA)_n}{(KV)_n^2} \quad (3)$$

In reference to the old [o] and the new [n] state, the impedance Z=K as constant.

$$Z = \frac{[Z_{p.u}]_o\,[KV]_o^2}{[MVA]_o} = \frac{[Zp.u]_n\;[kV]_n^2}{[MVA]_n} \quad (4)$$

Where both possess the same voltage level, $[KV]_o = [KV]_n$

$$\frac{[Z_{p.u}]_o}{[Z_{p.u}]_n} = \frac{[MVA]_o}{[MVA]_n} \quad (5)$$

From the power equation

$$|SCC| = \frac{[V_T]^2}{Z_T} = \frac{S_b}{|Z_T|}\,(MVA) \quad (6)$$

$$I_{FLA} = \frac{|SSC|_{3\varphi} \times 10^6}{\sqrt{3} \times V_L \times 10^3} \quad (7)$$

Also;

$$\text{Fault MVA} = \frac{Base\ MVA}{Z_{p.u}\ upto\ point\ of\ fault} \quad (8)$$

$$\text{Fault current } (I_F \text{ or } I_{SC}) = \frac{Fault\ MVA}{\sqrt{3} \times KV} \quad (9)$$

Where:

MVA: Rated Power
MVA_b or S_b: Base Rated Power
KV: Line Voltage
KV_b: Base Line Voltage
Z: Actual Impedance
Z_b: Base Impedance
Z% : Percentage Impedance
Z_{PU}: Per Unit Impedance
I_{FLA}: Rated Current or Full Load Current
I_{SC} : Short Circuit Current
I_F: Fault Current
$I_{B:}$ Base Current
SCC: Short Circuit Capacity

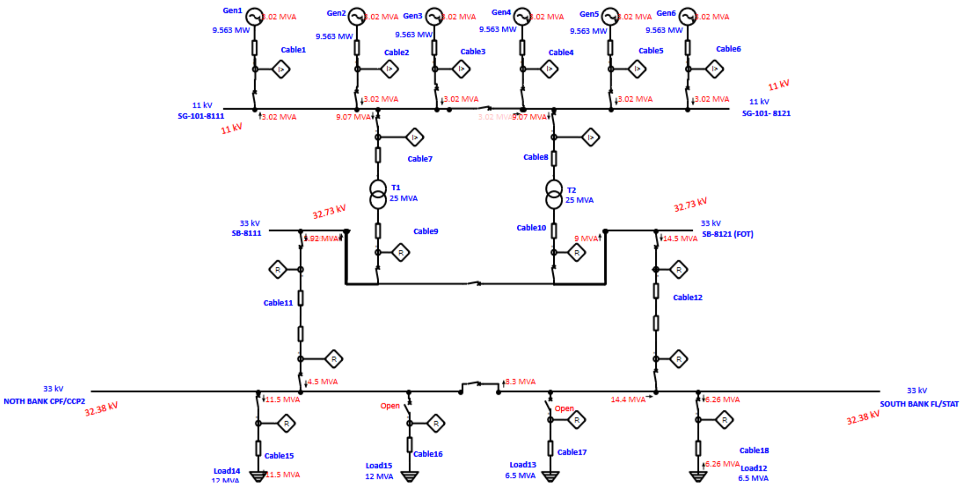

Figure 2(a): Load Flow Analysis of the SPDC Forcados Network.

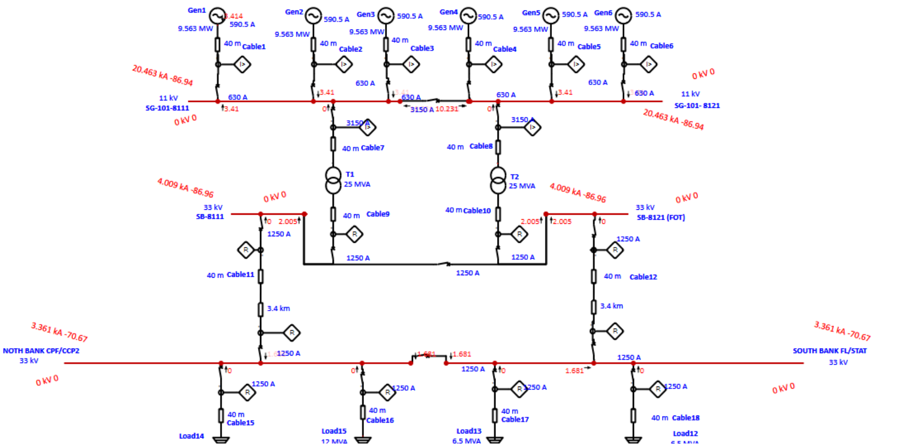

Figure 2(b): ETAP Simulation of Short Circuit Analysis of the SPDC Forcados Network.

2.3 Coordinated System of SPDC Forcados Network.

It is generally known that the magnitude of fault current is inversely proportional to the operating time of OCR of which the inverse time-delay OCR is used mostly in distribution network. Some of the parameters used in relation with the operating characteristics are; the relay pick-up (I_P) and the time delay setting (TDS).

$$t = \frac{a\ .TDS}{\left(\frac{I_{SC}}{I_P}\right)^{\beta} - 1} \qquad (10)$$

Moreover, the Plug Setting Multiplier (PSM) = I_{SC}/I_P ; and the value of α *and* β are dependent on the protection characteristics as shown on Table 1below.

Table 1: IEEE and IEC Constant of Relay Curves

Curve type	α	β
standard inverse	0.02	0.14
Very inverse	1.0	13.5
Extremely inverse	2.0	80.0
Long-time inverse	1.0	120.0

Based on IEEE and IEC standards, the inverse current characteristics curve of OCRs uses the PSM in steps of 25%, ranging from 50% to 200%, this differs depending on the type of inverse OCR characteristics curve. From (10) we can then deduce (11) that:

$$t = \frac{\alpha K}{(PSM)^{\beta} - 1} \qquad (11)$$

The minimum summation of coordination time of all associated relays are as shown in (12):

$$min\ \ T\ =\ \ \sum_{i=1}^{m} C_i\, K_i \quad (12)$$

Where, $C\ =\ \frac{\alpha}{(PSM)^{\beta}\ -1}\ \ and\ \ \ K = TDS$

It is important to note that the relays R1, R2, R3…… R4-3 were all configured based on the full load capacity of electrical devices such as transformers, generators and motors.

2.4 50/51 (OCR) Coordination with ETAP.

With instantaneous over current relays setting of downstream at lower current, correct discrimination is achieved than relays at upstream, this implies that the current setting of the relay closer to the source must be greater than the setting of preceding relays. Data for OCR coordination is as follows:

Fault level (I_F) at Bus 3-1 = 0.846KA
Fault level (I_F) at Bus 3-2 = 0.855KA
Fault level (I_F) at Bus 2-2 = 0.921KA
Fault level (I_F) at Bus 1-2 = 3.41KA

From (3.11), $t = \frac{\alpha K}{(PSM)^{\beta}_{-1}}$, Where α is 0.14 and β is 0.02 for standard inverse relay settings, PSM (plug setting multiplier) or (fault current/pickup current).

It is assumed that the time of operation (DOWNSTREAM) to be 0.5sec, the pick-up current which is also the full load current (FLA) of the associated device (12MVA load), FLA = 210 and the CT is rated 600:1. It is mostly seen as 125% of the rated current. I_F at Bus 3-1 is 0.846KA

For $R_{(4-2)}$ settings,

$$t\ \ =\ \ \frac{0.14\ \ x\ \ T_D}{\left(\frac{846}{210}\right)^{0.002}_{-\ 1}}\ \ =\frac{0.14T_D}{4.03\ ^{0.02}_{-\ 1}}\ \ =\ \ 4.95T_D$$

Since t = 0.5s, TD = 0.5/4.95 = 0.1009 ≈ 0.1

Let consider the trip time of $R_{(4-2)}$ with time dial 0.1and fault range as follows:

I_{Fmin} = 846Amps, R_{4-2} trips at 0.5sec, I_F = 1259Amps, R_{4-2} trips at 0.38sec, I_{SC} = 2937.1Amps, R_{4-2} trips at 0.26sec. If R_{4-2} is required to trip at 0.1sec at I_{SC},

Then,

$$t\ \ =\ \ \frac{0.14\ \ x\ \ T_D}{\left(\frac{2937.1}{210}\right)^{0.002}_{-\ 1}}\ \ =\ \ 2.58T_D$$

TD =0.1/2.58 = 0.0386 ≈ 0.04.

This implies that TD of R_{4-2} must be configured to 0.04 for the relay to at 0.1sec at a fault level of I_{SC} = 2937.1A.

For R_{4-3}:

This is also at same potential as R_{4-2} but different load.

I_n = 113.72A (pickup current), I_F = 0.855KA (Bus 3-2), PSM = 7.52, Trip time set = 0.5sec. Substituting the above data into equation 3.11.

Thus:

$$TD = \frac{T(PSM^{0.02}\ \ -1)}{0.14} = \frac{0.5(7.52^{0.02}\ \ -1)}{0.14} = 0.15$$

For R_{3-4} (Line 2-3):

I_n = 438A (pickup current), I_F = 0.921KA (Bus 2-2), PSM = 2.1, Expected operating Trip time set = Operating time of the downstream R_{4-2} / R_{4-3} (0.5sec) plus the Coordination Time Interval (CTI = 0.5sec).

Similarly;

$$TD = \frac{T(PSM^{0.02}\ \ -1)}{0.14} = \frac{1.0(2.1^{0.02}\ \ -1)}{0.14} = 0.11$$

For R_{3-2} (Line 2-3) (backup to R_{3-4} (Line 2-3)):

I_n = 438A (pickup current), I_F = 0.921KA (Bus 2-2), PSM = 2.1, Expected operating Trip time set = Operating time of R_{3-4} (1.0sec) plus the Coordination Time Interval (CTI = 0.5sec).

Similarly;

$$TD = \frac{T(PSM^{0.02}\ \ -1)}{0.14} = \frac{1.5(2.1^{0.02}\ \ -1)}{0.14} = 0.16$$

For R_{2-4} (CT 600:1):

I_n = 438A, I_F = 0.921KA, PSM = 2.1, Expected operating Trip time set = 1.5sec + CTI of 0.5sec.

Similarly;

$$TD = \frac{T(PSM^{0.02} - 1)}{0.14} = \frac{2.0(2.1^{0.02} - 1)}{0.14} = 0.21$$

For $R_{2\text{-}2X}$ (CT 2000:1) -11KV:
I_n = 1320A, I_F = 3.41KA, PSM = 2.58, Expected operating Trip time set = 2.0sec + CTI of 0.5sec.
Similarly;

$$TD = \frac{T(PSM^{0.02} - 1)}{0.14} = \frac{2.5(2.58^{0.02} - 1)}{0.14} = 0.34$$

For $R_{1\text{-}5}$ (CT 2000:1) -11KV:
I_n = 590.50A, I_F = 3.41KA, PSM = 5.77, Expected operating Trip time set = 2.5sec + CTI of 0.5sec.
Similarly;

$$TD = \frac{T(PSM^{0.02} - 1)}{0.14} = \frac{3.0(5.77^{0.02} - 1)}{0.14} = 0.76$$

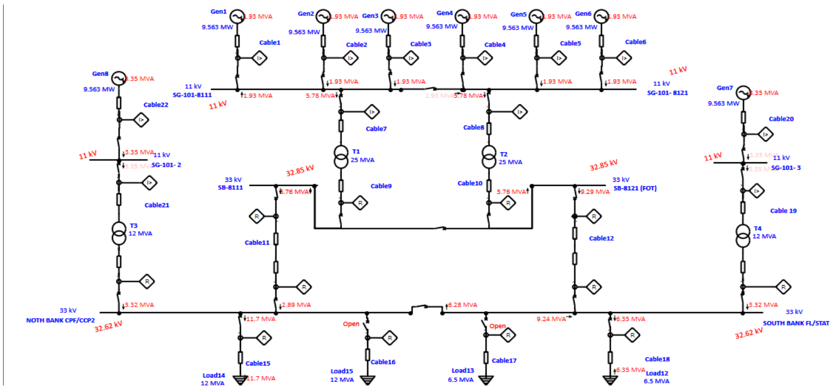

Fig 3(a):ETAP Simulation of Load Flow Analysis (FOT Network) After Introducing DGs

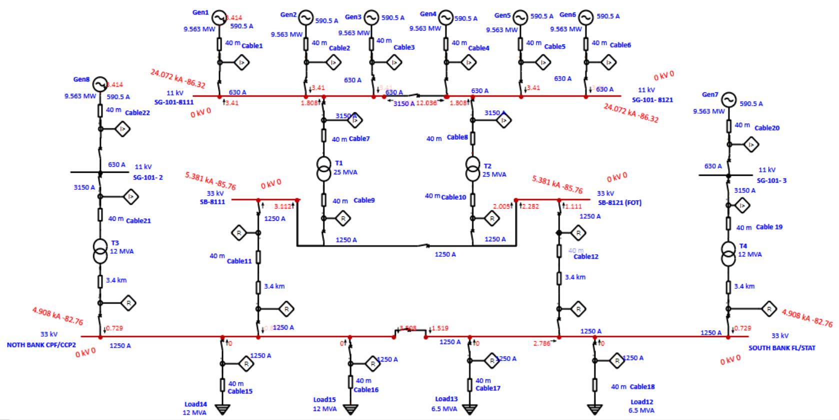

Fig 3(b):ETAP Simulation of Short Circuit Analysis (FOT Network) After the Introduction of DGs

III. RESULTS AND DISCUSSION

3.1 Results

The load flow analysis in Figure 2(a), shows that when the DGs has not yet been introduced the MVA value at the upstream 11KV bus was 9.07, and at the downstream 33KV bus was 4.5. But in Fig 3(a), when the DGs where introduced into the network, the MVA value at the upstream 11KV bus became 5.78 and at the downstream 33KV bus it became 3.32. These results show the improvement in power loss reduction due to the introduction of DGs. The short circuit current analysis in Fig2(b)shows the level of current 20.463 kA at the upstream and 3.361 kA at the downstream, and then after introducing DGs in Fig 3(b) the values became 24.077 kA at the upstream and 4.908 kA at the downstream. These results show an increase in the fault current contribution due to introduction of the DGs, thus need for re-coordination.

Table 2: I_{sc} and F_{MVA} Results from Load Flow and Short Circuit Analysis for different Buses

BUS	VALUES OBTAINED BEFORE THE INTRODUCTION OF DGs		VALUES OBTAINED AFTER THE INTRODUCTION OF DGs	
	I_{SC} (KA)	F_{MVA} (MVA)	I_{SC} (KA)	F_{MVA} (MVA)
11KV SG-101-8111/SG-101-8111	20.463	9.07	24.077	5.78
33kv SB-811 & SB-8121	4.009	9.0	5.381	5.76
33kV NORTH BANK CPF/CCP2 & SOUTH BANK FL/STAT	3.361	4.5	4.908	3.32

IV. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

Generically, there are numerous methods and techniques for calculating short circuit currents, but the P.U impedance method was used for these project. The ETAP simulation showed that system fault level at the upstream (Bus 101-8111 and Bus 101-8121) is much more than the individual short circuit current of each generator due to its associated percentage impedance. This led to the introduction of DGs to the 33KV switchyard of the power network of Forcados Terminal (FOT), to suffice in a case where there is a fault at the upstream leading to power outage.

From the results obtained it was seen that after the introduction of DGs the fault current increased, and thus the coordinated system was disrupted. There was also minimal fault MVA values, thus successfully improving the power transfer capacity and efficiency of the network. This is to say that this method of introducing DGs to the network at its feeding end is recommendable to a large extent.

4.2 Recommendations.

➢ Faults analysis and protection coordination analysis should be done at the initial-planning stages of a power network system.

➢ Power station should undergo the required tests before pre-commissioning and commissioning them also, routine tests and system performance should be assessed every five years to know load growth.

➢ FOT power distribution network should incorporate DGs at the load end of the network.

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