PROPOSED ADAPTIVE OVERCURRENT PROTECTIVE RELAYING IN A RELIABLE MICRO-GRID SYSTEM

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Abstract: A refinement to the way that overcurrent (O/C) protection of Inverse Minimum Time (IDMT) characteristic is applied in order to achieve reliable operation of a power system that contains Distributed Generation (DG) is required. This system is a micro-grid system marred with complexities of bidirectional power flow which the earlier generations of relays were not capable of dealing with. This paper investigates the application of adaptive O/C protection for effective selectivity, proper co-ordination of tripping and generally, proper management of increased fault levels introduced with connection of DG into the grid. Incorrect tripping has always resulted in nuisance tripping of circuit breakers deterring productivity, upsetting end-users and even posing a risk to life. Directional overcurrent protection is applied in Intelligent Electronic Devices (IED's) and prove through simulations that correct coordination of cascaded breakers in a mesh system is achieved with minimal disruption of supply. Different settings groups are applied to an IED relay and a seamless migration between settings groups is achieved though relay input logic.

Key words: Overcurrent, IDMT, Standard Inverse, IED, security of supply, Distributed Generation (DG), adaptive protection, dynamic protection.

1. INTRODUCTION

The dilemma posed by the two ends of the reliability spectrum can only be resolved by having more dynamism in protection schemes [1]. Abdelaziz et al defined adaptive protection as the ability of the protection system to automatically alter its operating parameters in response to changing power system conditions, to provide reliable relaying decisions [2]. Changes that require adaptability are topology changes, e.g. Distributed Generation (DG), operating mode change; fault conditions in the power system or load changes. Thorp et al. asserts that many relays are adaptive to a limited extent, referring to many protection functions as it were. A good example is IDMT overcurrent and earth-fault, which adapts its trip time to the current level. The IDMT function was first applied in electromechanical relays, e.g. the General Electric Company (GEC) CDG series of relays, and it has carried over to the subsequent generations of relays; the solid state and furthermore to numerical relays and IED's. This makes it one of the first in adaptive type protection, yet it has limitations of its own. [1-4]

One limitation in the development and application of protection relay settings is that relay settings are developed offline and are invariably in operating. This poses a challenge when the changes mentioned above are introduced in the power system. To this end, much effort has been put into making traditional protection functions adaptive by using intelligent devices and having advanced control circuitry. A control circuit is what makes a difference between current adaptive protection and traditional current [4].

This paper seeks to influence change in protection application philosophy by consideration of the requirement for reliability in a micro-grid system. The change will see IDMT O/C protection being adaptive in response to the connection of DG into the power grid. This is required as a means to manage the increased fault levels so that it does not become a barrier to the increased penetration of DG's. The results of this study should give comfort to the network operator about the dependability of the network and to the consumer about the security of supply when the solutions discussed here are applied.

The paper is arranged as follows:
Section 2 deals with the Experiment Set-up.
Section 3 deals with the System Model.
Section 4 is the Results Analysis and
Section 5 is the Conclusion.

2. EXPERIMENT SETUP

As at April 2016 the 102 Independent Power Producers have been procured by the South African Power Utility Company – Eskom, to the value of 6400 MW [10]. It is a clear indication of the extent to which DG has penetrated the power utility in South Africa. To this end, the conditions for interconnection to the Eskom grid have remained rudimentary, so has the protection settings philosophies [5].

The National Energy Regulator of South Africa (NERSA) distribution network code stipulates only four conditions for co-generation;

- Voltage Regulation – to guard against overvoltage,

- Power Quality constraints – to limit frequency variations,
- Combined short circuit contributions not to exceed the network design value and
- It is to be equipped with phase and earth fault protection [4] [5].

For the purpose of this study, a meshed network was selected. In such a network it is difficult to achieve proper relay coordination due to the bi-directional flow of power introduced by the presence of DG in the form of renewable solar photo voltaic (PV) power plant. Due to the voltage levels in the distribution network and also for the purpose of voltage regulation, there are transformers in the renewable plant. This is an important factor because it contributes to the increase in fault levels.

It is therefore essential to monitor the state of the plant, when it is online and out of service and apply that information as input to the IED. This can be used to dynamically change settings groups with the IED. The setting group change will result in the relay becoming directional or non-directional as may be required to achieve proper selectivity in fault isolation.

The two scenarios are depicted below:

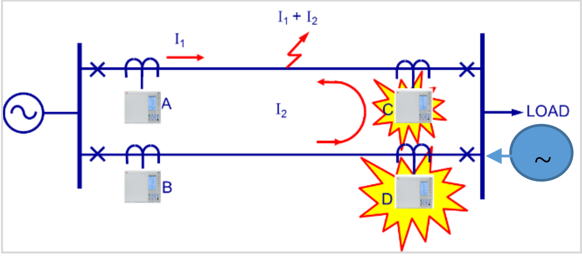

Figure 1: C and D relays non-directional

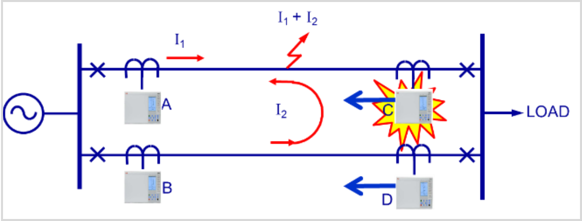

Figure 2: C & D relays directional

Figure 1 and 2 respectively, show the non-directional overcurrent and directional overcurrent. It would be desirable to operate with non-directional O/C when embedded generation is in circuit and then migrate to directional overcurrent when embedded generation is taken out of circuit. This ensures that supply to the load is secured and protection is selective.

The network used in this experiment is shown in the Figure 2 below. It is a mesh network supplied from the traditional power grid and consists of a renewable source.

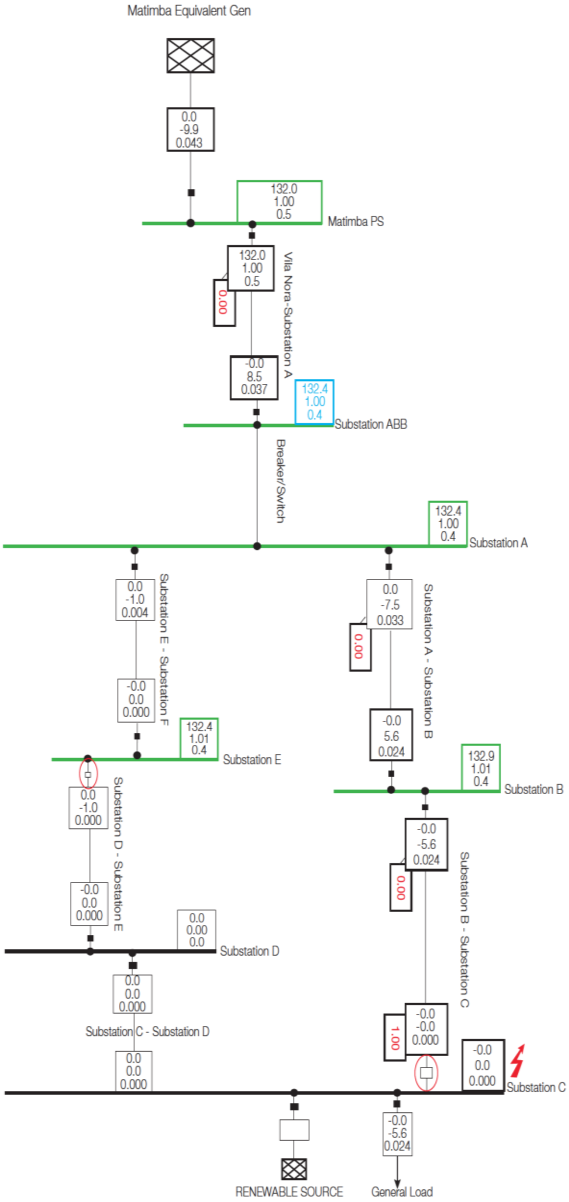

Figure 3: Network used in the experiment

The parameters of the network are as shown in Table 1 below:

Table 1: Network Parameters

	Length	Z1'Ω	phi Z1 (deg)	Z0'Ω
PS-Substation A	20	6.37	72.991	26.603
Substation A - Substation B	30	10.223	74.009	35.046
Substation B - Substation C	80	25.481	72.991	106.414
Substation C - Substation D	34.29	10.922	72.991	45.612
Substation D - Substation E	29	9.882	74.009	33.878
Substation E - Substation F	14.7	4.682	72.991	19.563

The relay settings and current transformers (CT) Ratios, re-engineered for proper co-ordination are shown in Table 2 and 3 below:

Table 2: CT Ratio, VT Ratio and Relay Type

Protection Type	Overcurrent
Current Transformer (CT) Ratio	500/1
Voltage Transformer (VT) Ratio	132000/110 V
Relay Type	ABB REF 615

Table 3: Settings at each substation

Substation	PS	TM	GroupSettings
Matimba	0.5	0.346	N/A
Substation A	0.5	0.111	Group 1: Non-Directional, Group 2: Directional
Substation B	0.5	0.089	Group 1: Non-Directional, Group 2: Directional
Substation C	0.5	0.05	Group 1: Non-Directional, Group 2: Directional

3. SYSTEM MODELLING

IDMT O/C is a time graded protection. For the calculations of the trip times in the Root Mean Square (RMS) simulations, the line parameters in the preceding section were used. The trip time for an International Electrotechnical Commission (IEC) Standard Inverse (SI) characteristic are given by the following equation:

$$\text{Required Trip Time} = \frac{0.14 \times \text{Time Multiplier}}{\left(\left(\frac{\text{Fault Current}}{\text{Plug Setting*Ct Ratio}}\right)^{0.02} - 1\right)} \qquad (1)$$

3.1 Steady State Analysis

In this analysis, a load flow is performed, followed by fault simulations. The objectives are the following:

- To prove that the relays are properly graded both in time and current through time curves.
- To determine the relay trip times based on the network parameters used.
- Compare the simulated trip times to the required setting trip times.

Once these were satisfactorily ascertained, the next step was to do the dynamic analysis.

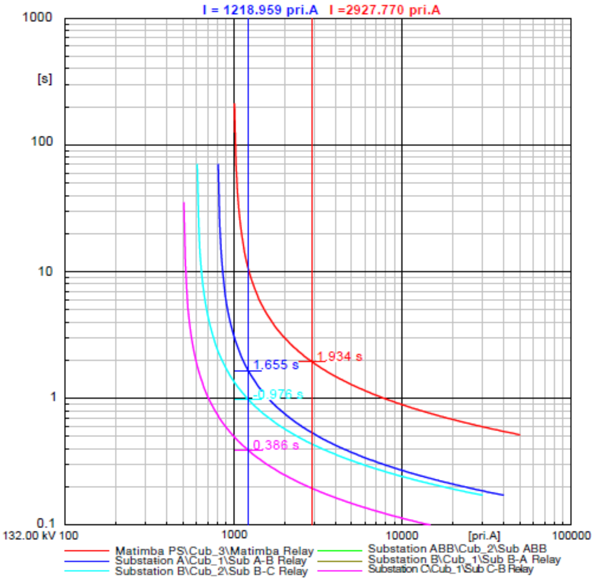

Figure 4: Time graded curves for dynamic simulations

3.2 Directional Relay Marshalling Problem - Algorithm

The IED has a standard marshalling matrix that has to be fashioned for directional faults. The quadrature method of detecting the direction of the fault is widely applied in protective relays and it operates as depicted in figure 5 below.

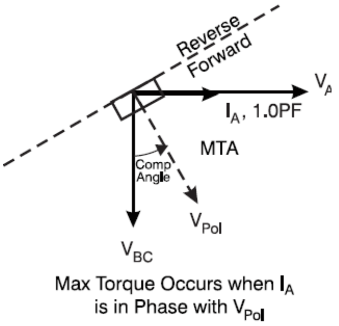

Fig. 5: Quadrature method for determining the direction of a fault [8]

Maximum Torque angle (MTA) or sometimes referred to as Relay Characteristic Angle (RCA) is the angle by which the applied voltage must be displaced to produce maximum sensitivity, this is meant to centre the relay characteristic.

Vpol is a fictive voltage and it is meant to be a “memory” voltage, fictive in the sense that it is not real but an imaginary quantity defined to give direction reference. It is set to last for a certain period of time – the validity period of the fictive Vpol. This time setting is the longest expected operating time for a three phase bolted fault.

3.3 Dynamic Analysis

A dynamic RMS 3 phase fault was simulated at the end of the feeder to determine which circuit breaker operates first to isolate the fault. The objective is to prove the coordination between the different circuit breakers in the network. The main focus here is to prove the correct tripping in the meshed network under the two conditions; with the DG in network and with DG out of the network. This is proven with group 1 setting, non-directional.

The simulation is repeated with group 2 settings, directional and the result is that the relays close to the fault did not operate as purposed to ensure continuity of supply to substation C from renewable source at C. A carrier signal will instantaneously be sent to the feeder breakers to Substation C (C-D and B-C) to open as a precaution to prevent the renewable supplying to the fault. In that way the load is sustained through the renewables. Once an investigation has been done and the fault has been cleared, the system can be brought back to normal operation.

Migration between the two groups of protection settings is achieved through logic inputs to the IED relays. This is provided for in the marshalling of the relays configured for this network, the ABB REF 615 relay.

4. RESULTS ANALYSIS

The results clearly show that there is sufficient coordination for a fault on the feeders as shown in Figure 5. The feeder with the applied overcurrent settings trips the relay in 1.069 seconds on a fault of 7 kA. All the other downstream relays do not see the fault as group 2 settings are in operation. It can also be seen from the dynamic time domain simulation the shovel break opens to isolate the fault as expected in 1.069 seconds. The time could not be exactly 1.2 seconds to the setting range that does not allow a time multiplier of less 0.05. It can be noted that for a fault higher than 7 kA, the grading margin of, typically 0.4 seconds, is flouted therefore the decision to use group 2 settings makes sense. A fault current 7 kA is the three phase fault current at substation C that takes into account the contribution of DG to the fault levels.

The relay trip logic should be in such a way as to consider factors relating to a fault at the furthest end of the network. When DG or embedded generation (especially PV generation) is connected at the consumption end of the network, it is necessary to isolate embedded generation from the network completely because of its combustibility nature of PV plant hence the application of non-directional O/C to trip upstream breaker (Matimba) at 1.069 s in this experiment.

Lern et al asserts that for the distribution network of up to 40 MVA peak of solar penetration, sympathetic tripping is unlikely, therefore no directional overcurrent is required [19].

The selection of settings group and migration from one group to another is achieved through the correct marshalling of logic input to the IED.

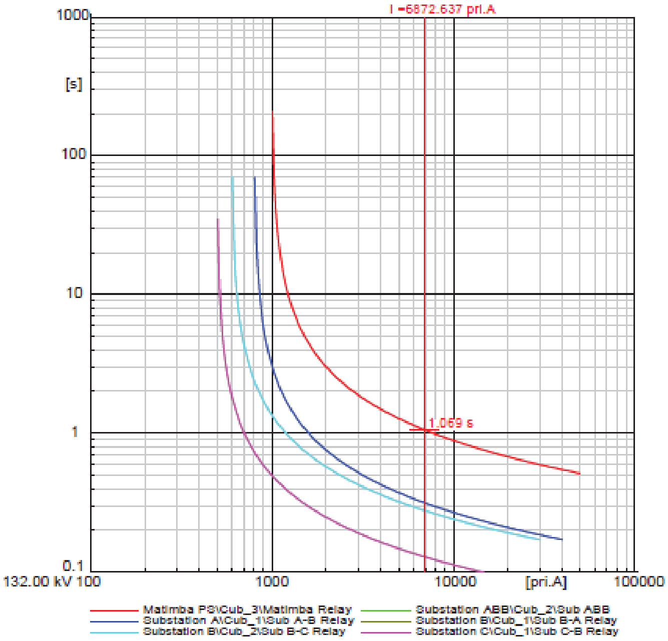

Figure 6: Time graded curves for dynamic simulations

5. CONCLUSION

It has been shown that proper coordination of protection tripping can be achieved, firstly with control of protection settings by centralising the function for proper management. This ensured that each substation or busbar setting is not calculated in isolation but the grading information is taken into account.

When DG was out of service, unidirectional power flow was unidirectional, therefore the applied O/C settings (group 1: directional) were applied, operating for a fault in the opposite direction to the power flow. This resulted in a quicker isolation of fault. The dependability of supply aspect of reliability was observed.

With DG in circuit, group 2 settings made it possible to achieve security of supply through the renewable source.

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