Impact of RDG Penetration on IDMT Overcurrent Relay Operation in Radial MV Distribution System

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***Abstract*--The connecting of renewable dispersed generation *RDG* to the medium voltage *MV* distribution power system has many advantages, However, as much *RDG* connected to the distribution power system as much the system are going to be complicated, So, in the presence of *RDG* some problems in protection devices will occur. By installing the *RDG* in power distribution system, the fault current levels I_F will be changed and furthermore may lead to a miscoordination in directional overcurrent relay *DOCR*. This paper focuses on a novel approach to study the impact of active power injected by *RDG* P_{RDG} on the different types of fault current I_F, and on the operation time *T* for *IDMT* over current relay in the presence of a three phase fault current and different types of characteristic curves of *IDMT*, for each impact two cases will be studied: power system with, and without *RDG*. This approach was developed using MATLAB, and has implemented on an Algerian *MV* radial distribution power system.**

***Index Terms*—Renewable dispersed generation (RDG), fault current (I_F), directional over current relay (DOCR), operation time (T), inverse definite minimum time (IDMT).**

2. INTRODUCTION

The classical electrical generation comprises of sizeable central power station, such as hydro, nuclear, and thermal. The distances between the stations and the loads are significant, for that reason, the transport of energy must be made by transmission lines and distribution systems from the power stations to the loads. So these distribution systems and stations and transmission lines are being used to their maximum capacity nowadays, but the demand of consumptions is increasing [1].

This increase in consumption demand needs the building of new generation power stations and an expanded transmission and distribution systems, this requirements are not recommended from an environmental or economic perspective [2]. Therefore, the integration of *RDG* in the distribution power systems has been increased rapidly [3]. *RDG* is determined as small-scale electrical generation supplied by the renewable energy sources, such as solar and wind, or by sources of low-emission energy, such as micro-turbines and fuel cells. Different forms of RDG technologies are developed around world in recent years [4]. Integration of the RDG into distribution power system has many advantages and benefits but it has also their enormous influences on the power system [5], one of the major impacts is the impact on the operation of the protection system [6].

Concerning the impact of RDG on protection, many researchers performed how to gear of the consequent problems of integrating of RDG. Some of these famous difficulties are: Arcing faults [7], Protective relaying scheme [8], cost reduction of distribution network protection [9], Operation of auto reclosing [10], Adaptive protection scheme [11], Fuse-Fuse coordination [12], Recloser-Fuse coordination [13], Single Line to earth faults [14], protection of single wire earth return lines [15], performance curve of frequency relays [16], protection coordination index [17], Earth fault protection with isolated neural [18], Fault location problem [19], Optimal allocation of DG to minimize relay operating times [20], traditional current protection [21], and distance relay zone settings [22].

This paper is arranged as follow, section 3 illustrate the basic equations needed for the calculation of the fault current with and without RDG, section 3 presents the properties of the IDMT overcurrent Relay and the needed equations and its different kinds of characteristic curve, section 4 presents the case study and the DISCUSES OF obtained results in two cases (with and without RDG).

2. CALCULATION OF FAULT CURRENT IN THE PRESENCE OF RDG

To illustrate the impact of *RDG* unit on the fault current I_F, a generic feeder is shown in Figure 1. The *RDG* unit is connected at distance d_{RDG}, and the three-phase fault current I_F located in the end of the feeder is simulated.

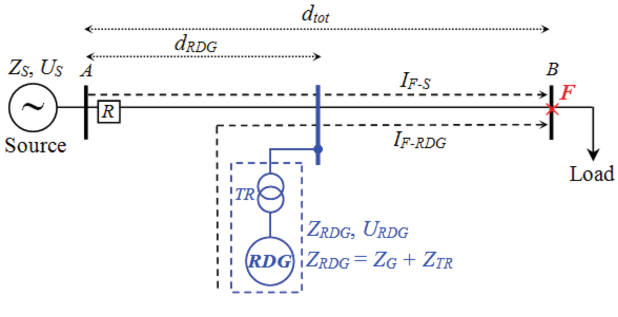

Fig. 1. Contribution of fault current in presence of *RDG*.

To specify the location of the *RDG*, The distance parameter is defined as:

$$\lambda = \frac{\delta_{P\Delta\Gamma}}{\delta_{\tau o\tau}} \tag{1}$$

Where, d_{tot} is the total feeder length, and l the relative RDG location. Figure 2 presents the electric equivalent of the Figure 1, where Z_L is the total line impedance, Z_S is the source impedance, Z_{RDG} is the *RDG* impedance, U_S the voltage of source, U_{RDG} voltage of the *RDG*.

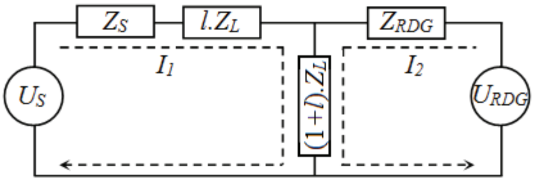

Fig.2. Electric equivalent circuit.

Determining the mesh currents I_1, I_2 and applying the law of Kirchhoff's voltage for U_{RDG} and U_S.

$$\begin{bmatrix} Y_{\Sigma} \\ Y_{P\Delta\Gamma} \end{bmatrix} = \begin{bmatrix} Z_S + Z_{RDG} & (1-l).Z_L \\ (1-l).Z_L & Z_{RDG}(1-l).Z_L \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} \tag{2}$$

Where, I_1 is the power system contribution of the $I_{F\text{-}S}$, I_2 is the *RDG* contribution of the $I_{F\text{-}RDG}$. To define the expressions for $I_{F\text{-}S}$ and $I_{F\text{-}RDG}$, the equivalent circuit of Thevenin of the feeder above is derived in Figure 3.

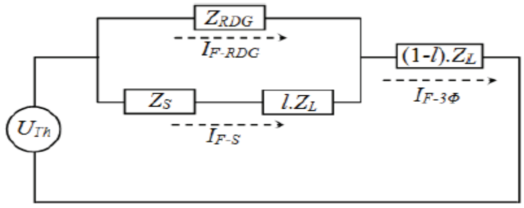

Fig. 3. equivalent circuit of Thevenin.

The Thevenin impedance is given as:

$$Z_{TH} = \frac{(Z_{\Sigma} + \lambda Z_{\Lambda}).Z_{P\Delta\Gamma}}{Z_{\Sigma} + \lambda Z_{\Lambda} + Z_{P\Delta\Gamma}} + (1-l).Z_{\Lambda} \tag{3}$$

The total three phase fault current:

$$I_{\Phi\text{-}3\phi} = \frac{Y_{TH}}{\sqrt{3}.Z_{TH}} \tag{4}$$

When substitute equation (3) into equation (4):

$$I_{\Phi\text{-}3\phi} = \frac{Y_{TH}.(Z_{\Sigma} + \lambda Z_{\Lambda} + Z_{P\Delta\Gamma})}{\sqrt{3}\left[A + B + X + \lambda Z_{\Lambda}(Z_{\Lambda} - Z_{\Sigma}) - l^2 Z_{\Lambda}^{2}\right]} \tag{5}$$

Where, the coefficients *A*, *B, C* are detrmined as:

$$Z_{\Lambda} Z_{P\Delta\Gamma} = A \tag{6}$$

$$Z_{\Sigma} Z_{P\Delta\Gamma} = B \tag{7}$$

$$Z_{\Sigma} Z_{\Lambda} = X \tag{8}$$

For the power system contribution holds:

$$I_{\Phi\text{-}\Sigma} = \frac{Z_{P\Delta\Gamma}}{Z_{P\Delta\Gamma} + \lambda Z_{\Lambda} + Z_{\Sigma}}\ '\ I_{\Phi\text{-}3\phi} \tag{9}$$

Substituting equation (5) into equation (9), gives the RDG contribution of the short circuit current:

$$I_{\Phi\text{-}\Sigma} = \frac{Y_{TH}.Z_{P\Delta\Gamma}}{\sqrt{3}\left[A + B + X + \lambda Z_{\Lambda}(Z_{\Lambda} - Z_{\Sigma}) - l^2 Z_{\Lambda}^{2}\right]} \tag{10}$$

The total short-circuits current $I_{F\text{-}3ø}$ given by equation (5) and the $I_{F\text{-}S}$ given by equation (9), are non-linear current. In case of a low power system, Z_S can be as large as Z_{RDG} and considering of the contribution of the generator, the power system contribution to the fault current reduces [1]-[2].

The equations of the three different type of fault current below are the basic equations used in this our study case illustrated by figure 5 and 6.

A. Equations of fault current without RDG

The Phase-ground fault current:

$$I_{F(ph-\gamma)} = \frac{\varsigma_{\nu}}{Z_1 + Z_2 + Z_0 + 3P_{\Phi}} \tag{11}$$

The Phase to phase isolated fault current:

$$I_{F(\pi\eta-\pi\eta)} = \frac{\varsigma_{\nu}}{Z_1 + Z_2} \tag{12}$$

The three Phase symmetrical fault current:

$$I_{\Phi(3\pi\eta)} = \frac{\varsigma_{\nu}}{Z_1} \tag{13}$$

Where Z_1, Z_2, Z_0, are respectively the positive and negative and homopolar sequence impedance, and R_F is the resistance fault to ground, and V_n the simple voltage

B. Equations of fault current with RDG

The total line impedance in the presence of *RDG*:

$$Z_{\Lambda-P\Delta\Gamma} = \frac{Z_{\Lambda} \times Z_{P\Delta\Gamma}}{Z_{\Lambda} + Z_{P\Delta\Gamma}} \tag{14}$$

$$Z_{P\Delta\Gamma} = \Xi_{\Gamma} + Z_{TP} \tag{15}$$

$$\Xi_{\Gamma} = \frac{Y_{P\Delta\Gamma}^{\ 2}}{\Pi_{P\Delta\Gamma}} \tag{16}$$

Where X_G is the interne reactance of generator *RDG* and, Z_{TR} is the impedance of the coupling transformer, U_{RDG} is the voltage at the *RDG*,and P_{RDG} is the active power injected by the *RDG*

The Phase-ground fault current:

$$I_{F(ph-\gamma)} = \frac{\varsigma_{\nu}}{Z_{\Lambda-P\Delta\Gamma.1} + Z_{\Lambda-P\Delta\Gamma.2} + Z_{\Lambda-P\Delta\Gamma.0} + 3P_{\Phi}} \tag{17}$$

The Phase to phase isolated fault current:

$$I_{F(\pi\eta-\pi\eta)} = \frac{\varsigma_{\nu}}{Z_{\Lambda-P\Delta\Gamma.1} + Z_{\Lambda-P\Delta\Gamma.2}} \quad (18)$$

The three Phase symmetrical fault current:

$$I_{\Phi(3\pi\eta)} = \frac{\varsigma_{\nu}}{Z_{\Lambda-P\Delta\Gamma.1}} \quad (19)$$

3. IDMT DIRECTIONAL OVERCURRENT RELAY

The essential task of the DOCR overcurrent relays is to sense the faults on the lines, and isolate these faults quickly by the opening of all the current ways. The sensing and the switching must occur rapidly to minimize the damage. However, it should be very selective. To increase the reliability, it has led to the practice of providing both "primary" protections with "backup" protections which should function only if one of the primary devices fails. On the basis of the operation the overcurrent relays are classified in three categories: *Instantaneous Overcurrent Relay* (IOR), *Definite Time Overcurrent Relay* (DTOC), *Inverse Definite Minimum Time* (IDMT) *Overcurrent Relay.*

A. *Inverse Definite Minimum Time* (IDMT) *Overcurrent Relay :*

This relay has an inverse time characteristic. This means that the operating time of the relay is inversely proportional to the fault current and if the fault current is higher, the operating time will be lesser.

It can be classified for a very large range of fault currents and operating times. The characteristic of an IDMT overcurrent relay depends on the type of standard selected for the relay operation. These standards can be: IEEE, ANSI, IEC or user defined. By using the characteristic curves and the corresponding parameters the relay calculates the operation time.

Any of the standards mentioned above can be used to implement the characteristic curve for an overcurrent relay. The overcurrent relay will then calculate the operation time corresponding to that particular characteristic curve [23]-[24].

B. Relay characteristics :

The directional overcurrent relays employed in this paper are considered as numerical with standard IDMT characteristics that comply with the IEC 60255-3 standard, and have their tripping direction away from the bus [25].

$$T = T\Delta\Sigma' \frac{K}{\left(\frac{I_M}{I_\Pi}\right)^{\alpha} - 1} \quad (20)$$

$$I_M = \frac{I_F}{K_{CT}} \quad (21)$$

Where, T is the relay operating time (sec), TDS is the time dial setting (sec), I_P is pickup current (A), I_F is the fault current (A), I_M is the fault current measured by the relay, and K_{CT} is ration of current transformer. The constant k and α that depends of characteristic curve for IDMT directional overcurrent relay.

However, it can be shown that the proposed method can be easily applied to a radial distribution power system with combination of overcurrent relays with different characteristics as presented in Figure 4.

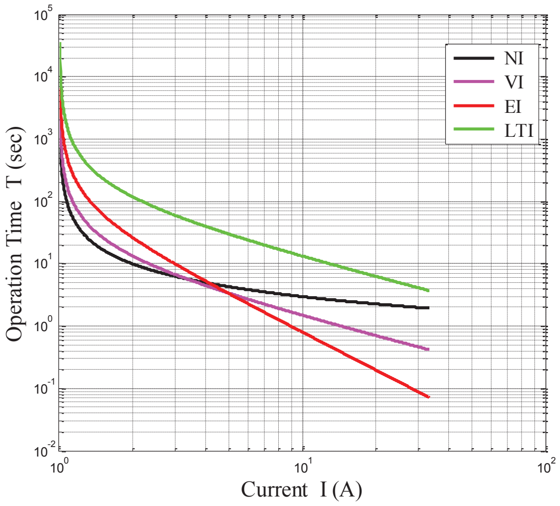

Fig.4. Time and current of IDMT Overccurent Relaying Characteristics.

Table 1 below shows the constants values corresponding to each curve characteristic made standard IEC 60255-3 :

TABLE I

Different type of inverse chracteristics curves

type	K	α
Normal Inverse NI	0.14	0.02
Very Inverse VI	13.5	1.00
Extremly Inverse EI	80	2.00
Long Time Inverse LTI	120	1.00

4. CASE STUDY AND SIMULATION RESULTS

The proposed methodology is applied to a medium voltage (30 kV) radial distribution power system.

Figure 5 show the main distribution feeder protected by IDMT relays R_A and R_B, and the fault on the bus C. on the other hand the RDG study is installed between buses B and C as shown in figure 6.

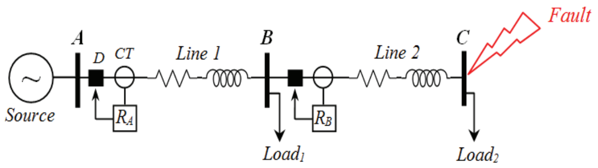

Fig. 5. Distribution network without RDG .

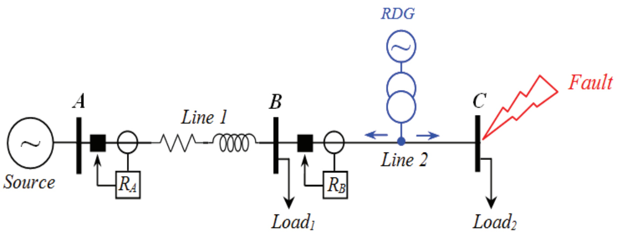

Fig. 6. Distribution network with RDG.

Based on the above unifilar schemes we will study the following impact:

A. Impact of P_{RDG} on fault current

Table II presents the absolute and angles values of the three types of fault current (I_F) on absence of RDG.

TABLE II

Fault Current without RDG

Fault type		Single Phase	Phase to Phase	Three-phase
I_F	Abs (kA)	0.8513	3.6863	4.2566
	Angle (°)	-81.093	-81.093	-81.093

Figure 7 shows the impact of the active power injected by RDG (P_{RDG}) on the fault current I_F in presence of the three types of fault current.

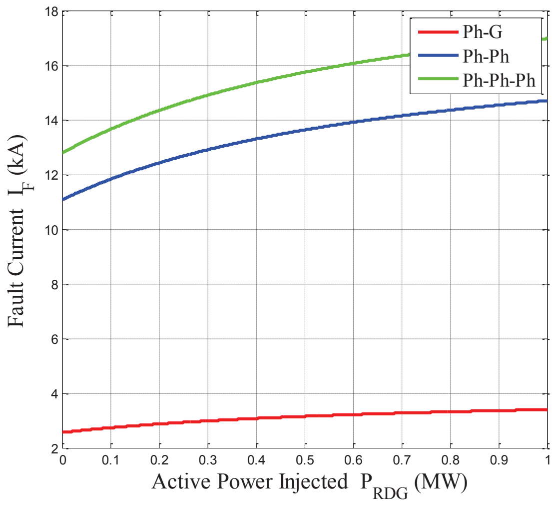

Fig. 7. Fault Current with RDG.

Following table II and figure 7, the value of fault current with RDG increases by augmentation of active power injected whatever the type of fault current, this is a consequence of the effect of the impedance of RDG Z_{RDG} where Z_{RDG} decreased by the injection of active power, then, the fault current I_F is being increased.

B. Impact of P_{RDG} on the operation time

Table III present the values of operation time for IDMT overcurrent relay R_B without RDG for the different types of characteristics curves with the three types of fault current on bus C.

TABLE III

Operation Time without RDG

Fault type		Single Phase	Phase to Phase	Three-phase
T (sec)	NI	6.6416	2.7210	2.5697
	VI	7.3459	1.1960	1.0236
	EI	11.3429	0.5334	0.3994
	LTI	65.2971	10.6309	9.0987

Figure 8 and 9 and 10 and 11 shows the impact of the active power injected by RDG on the operation time for IDMT overcurrent relay R_B in the presence of the three types of fault current in the different types of characteristics curves respectively NI, VI, EI, LTI.

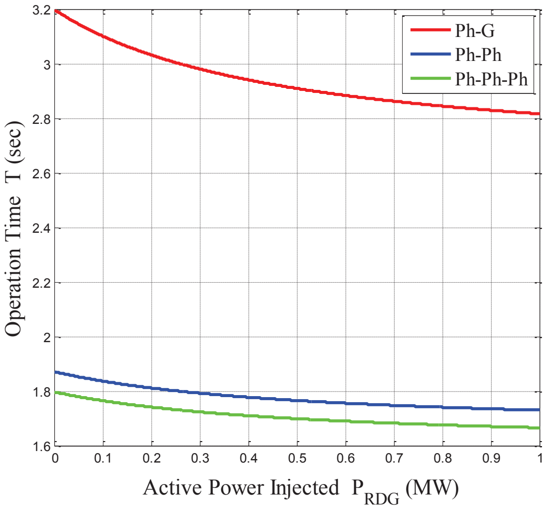

Fig. 8. Operation Time of NI characteristic curve with RDG

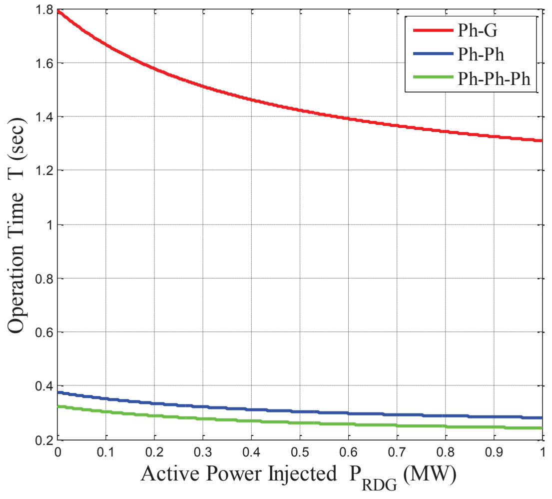

Fig. 9. Operation Time of VI characteristic curve with RDG

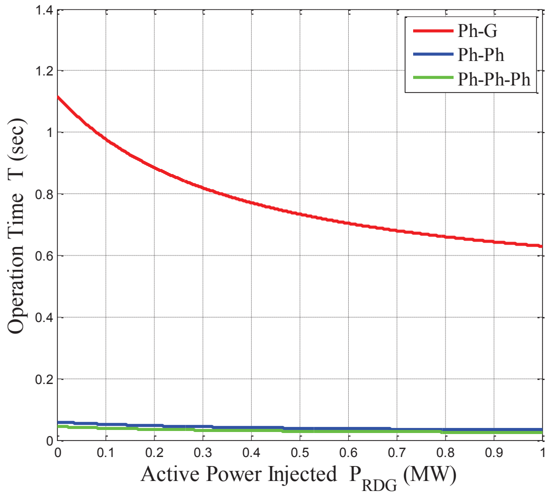

Fig. 10. Operation Time of EI characteristic curve with RDG

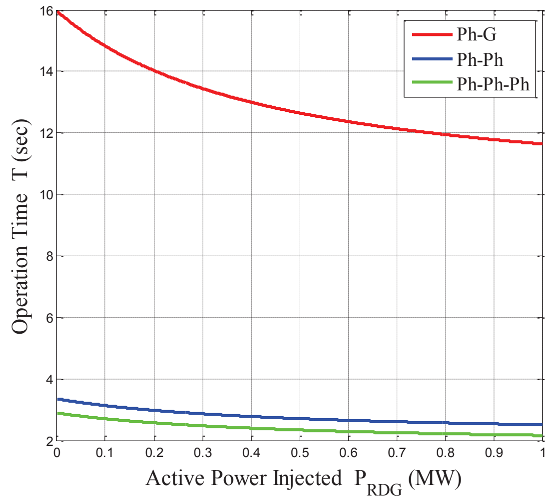

Fig. 11. Operation Time of LTI characteristic curve with RDG

Following the figures 8, 9, 10 and 11and the table III whatever the type of characteristic curve and the type of fault current the presence of the active power injected of RDG decrease the value of operation time of relay because the fault current I_F is changed.

5. CONCLUSION

This paper fills a gap in the understanding of the particular problem of protection blinding through presenting a detailed study of the impact of RDG on IDMT directional overcurrent protection using a typical MV radial distribution network in presence of three phase fault. The factors that can influence the effect of *RDG* on the fault current and the operation time value for overcurrent protection system have been carefully considered in the investigation. By installing *RDG* in MV power distribution networks, the fault current levels are changed and may lead to some mis-coordination in directional overcurrent protection.

The continuity of this work will be the coordination of the IDMT overcurrent relays considering several conflicting objective functions and various power system topologies in presence of FACTS devices and renewable energy using optimization technique.

APPENDIX

A. MV Distribution Line

U_n = 30 KV,
L_{AB} = 20 KM,
L_{BC} = 10 KM,
Z_L = 0.021 + j 0.134 Ω/KM,

B. Renewable Dispersed Generation (RDG)

U_G = 660 V,
P_{RDG} = 0 à 1 MW,
Z_{TR} = 0.1254 + j 0.2457 Ω/KM,

C. Directional Overcurrent Relay

K_{CT} = 300/1,
Standard: IEC,
TMS = 1.00 (sec),
I_P = 1.00 (A),

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