COMPENSATION OF DGs IMPACT ON OVERCURRENT PROTECTION SYSTEM OF SMART MICRO-GRIDs

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ABSTRACT

Traditional distribution networks have radial and unidirectional topology. The protection system of these networks is based on time and current coordination of overcurrent protection devices, which are negatively affected by DGs. The coordination of these devices is the most important issue of the protection system. DGs increase the voltage of faulted feeders at their connection point and cause the underreach in the time inverse characteristic of overcurrent protection devices. In this paper, a self-adaptive method for smart micro-grid is proposed, which compensates the underreached fault current seen by the relay. Therefore, there is no need to change the settings of protection devices for different operation conditions.

INTRODUCTION

Distributed Generation (DG) alongside the traditional generation is implemented as an appropriate alternative to supply consumers. Usually, DGs are connected directly to distribution feeders and their integration in the distribution network can result in the micro-grids concept [1]. A micro-grid is a part of a distribution system, which contains a few distributed energy resources (DER). The micro-grid can be isolated from the utility and continuous working in an island mode [2].
Traditional distribution networks have a radial and unidirectional topology. The protection system of these networks is based on the time and current coordination of overcurrent protection devices affected by DGs [3]. The protection system of distribution networks contains time inverse overcurrent devices including relays, reclosers and fuses. The coordination of these devices is the most important challenge for the protection system. DGs affect the performance of protection devices and can cause the protection system maloperation as follows:

- Undesired trips [4]
- Overcurrent protection devices underreach [5]
- Undesired islanding [6]
- Loss of coordination including relay to relay, fuse to fuse and fuse to recloser
- DGs undesired outages

In order to overcome these problems, some recent works are presented. Traditional protection will be subjected to a few new developments. The first and simple one is changing all protection devices and their settings which is so costly and economically irrational. There is no tendency to this solution. Also, this proposal is rejected because the protection devices settings should be changed for each generation condition and the replacement of devices is not feasible [7].
Another alternative solution is the application of the Fault Current Limiter (FCL) in series with any DG. Whenever a fault occurs, the FCL impedance increases so that the DG fault current can be limited. Thus, DG has no effect on the short circuit currents and the protection system can operate the same as the traditional one [8].
The fault location is used to fault clearing as discussed in [9]. Finally, as an acceptable and available alternative solution, the adaptive protection schemes are widely noted in recently works [10]. These protection schemes are based on the local or non-local information. The adaptive local protection updates protection devices settings based on the local information, but non-local information based adaptive methods gathers information through the smart grid infrastructures from all over the power grid.
In this paper, it is focused on an adaptive method based on wide area measurements. In the proposed method, an adaptive protection scheme compensates the underreached fault currents seen by overcurrent protection relays. In the smart grid based proposed method, there is no need to change the settings of protection relays for different operation conditions because this solution uses an online compensation for the DGs impact on the overcurrent protection system. Actually, the currents seen by relays are increased as much as DGs decrease them. Thus, the fault currents seen by relays are the same as the case with no DG. The compensation depends to fault type which is detected based on available works [11]. The Compensation algorithm is adaptively selected based on the detected fault type and fault location. As will be presented in the following sections, the principles of compensation are mathematically discussed and the analyses is implemented for two most important scenarios (three phase to ground and single phase to ground faults) for different fault location and DGs condition. The effectiveness of the proposed method is presented based on PSCAD/EMTDC simulations.

PRINCIPLES AND SIMULATIONS

The underreach phenomenonon occurs in grid connected micro-grids. In island mode, utility does not supply the micro-grid internal faults. On the other hand, DGs approximately have the same short circuit capacity range. Thus, the overcurrent protection system of an islanded micro-grid is obtained the same as a main grid but with less pickup values. In this paper, the underreach phenomenon is investigated only in grid connected mode of operation of the test micro-grid. The micro-grid mode of the operation is detected through an online method using (df/dt) [10]. For grid connected mode of operation, the traditional settings of relays are adaptively selected and the DGs impact on these settings (underreach) is compensated by the proposed method. If the micro-grid is isolated from the utility, then the settings are adaptively changed to island mode designed protection system settings. Here, in order to compensate the underreach impact of DGs, there is no need to consider any protection system. Once the fault currents seen by overcurrent relays are the same as the case with no DGs, it can be said that the underreach impact of DGs has been compensated. In the grid connected micro-grid, once any fault occurs on the feeders, the currents seen by relays abnormally rise. Thus, the fault detection mechanism is enabled and the fault classification mechanism begins to detect the fault type. The compensation is calculated via KVL of positive, negative and zero sequence networks depending to fault type. The calculated compensated current is digitally added to relay measured current in the secondary side of current transformers and the underreach of the relay is corrected. The compensation procedure is discussed for two scenarios in the following sections and the simulation results are presented.

Test System Model

The micro-grid test system is presented in Fig .1. This system is a part of a distribution network, of Himmerlands Elforsyning, in Aalborg, Denmark. All data about distribution lines, loads and wind turbine generators (WTG) simulation have been presented in [10]. The overcurrent protection relays are supposed to operate based on IEC 255-3 (normally inverse) time over current characteristics. The proposed compensation approach is studied for different fault locations and DGs operation conditions.

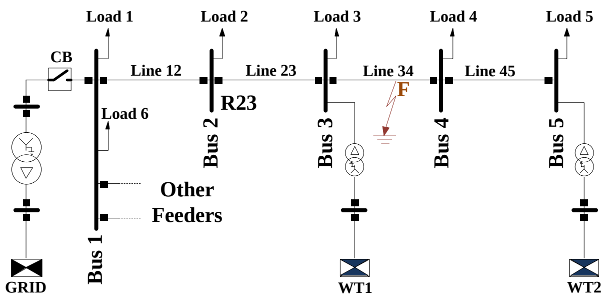


Fig. 1. Test system model of the micro-grid.

Three Phase ABC to Ground Fault

In this scenario, a three phase ABC to Ground fault (F) is considered. In the proposed method, the fault type is detected through an online method based on [12]. But the fault location and fault resistance are unknown. In order to calculate the compensation term of relay current, these two unknown parameters must be calculated. Thus the relevant positive sequence network is considered for the detected fault type which is presented in Fig .2.

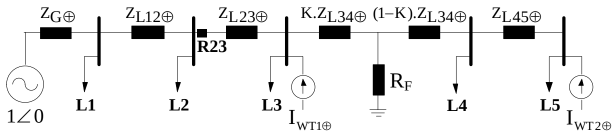


Fig. 2. Positive ssequence network for ABCG fault condition.

The KVL is carried out and the real and imaginary parts of this KVL construct two equation with only two unknown including fault location K and fault resistance R_F as the following equation.

$$(Z_{G\oplus} + Z_{L12\oplus} + Z_{L23\oplus}).I_{R23\oplus} + K.Z_{34\oplus}.(I_{R23\oplus} + I_{WT1\oplus}) + ...$$
$$... + R_F.(I_{R23\oplus} + I_{WT1\oplus} + I_{WT2\oplus}) = 1\angle 0 \quad (1)$$

Equation (1) can be rewritten as follows:

$$K.(A) + R_F.(B) = C \quad (2)$$

Equation (2) contains complex multiplies. Thus both sides of this equation have real and imaginary parts. On the basis of mathematical principles, the real and imaginary parts of two side of this equation must be equal.

$$K.(A_R) + R_F.(B_R) = C_R \quad (3)$$
$$K.(A_{Im}) + R_F.(B_{Im}) = C_{Im} \quad (4)$$
$$K = (B_{Im}.C_R - B_R.C_{Im})/(A_R.B_{Im} - A_{Im}.B_R) \quad (5)$$
$$R_F = (A_R.C_{Im} - A_{Im}.C_R)/(A_R.B_{Im} - A_{Im}.B_R) \quad (6)$$

The fault current seen by R_{23} is totally as follows including the underreach component. Term I_{FN} for no DG case and I_U for DG penetration and thus underreach case study.

$$I_F = I_{FN} - I_U \quad (7)$$

Thus the underreach Term I_U is calculated through the Kirchhoff's principles as follows and is added to current seen by relay R_{23} which is underreached.

$$I_U = \frac{K.Z_{34\oplus}.I_{WTG1\oplus} + R_F.(I_{WTG1\oplus} + I_{WTG2\oplus})}{Z_{G\oplus} + Z_{L12\oplus} + Z_{L23\oplus} + K.Z_{34\oplus} + R_F} \quad (8)$$

The fault location K is assumed to be forward the R_{34}. If the K be negative, then the I_U is obtained as follows.

$$I_U = \frac{R_F.(I_{WTG1\oplus} + I_{WTG2\oplus})}{Z_{G\oplus} + Z_{L12\oplus} + K.Z_{L23\oplus} + R_F} \quad (9)$$

The Term I_U is actually the negative effect of WTGs. This term is calculated as above and is added to relay measured current. Thus the underreach phenomenon occurred in R_{23} overcurrent relay is compensated.

The test system model of the mentioned micro-grid is simulated in PSCAD/EMTDC environment and the proposed method is investigated for different fault locations to overcurrent relay R_{23} place (K= +50, +10 and -50 present of line34) and also for different power generation of

WTGs (0.5, 1 and 2MW). The R_F is considered as constant which should be analysed as another effective parameter. The fault currents seen by R_{23} is corrected and DGs impact is compensated as presented in Fig .3.

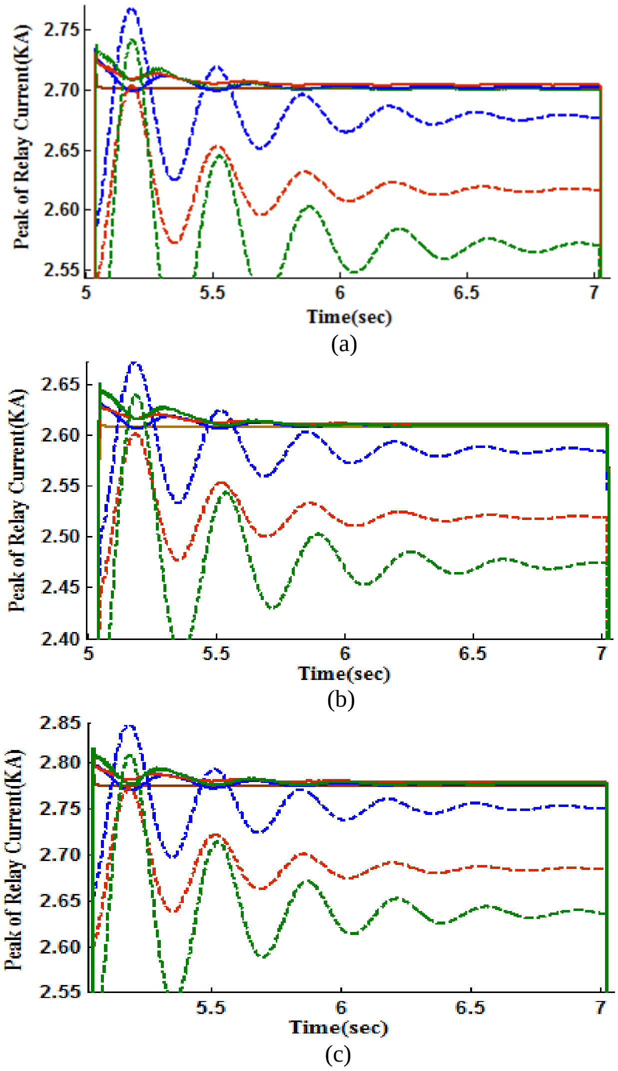


Fig. 3. Currents seen by R23 for ABCG fault. Dotted line for uncompensated currents and bolds for compensated. Brown for no DG case, Blue for WT1=0.5MW and WT2=0MW, Red for WT1=2MW and WT2=0MW and finally green for WT1=2MW and WT2=1MW, (a) K=+10%, (b) K=+50% and (c)K=-50%.

Phase A to Ground Fault

Here, a single phase to ground (AG) fault occurs in different conditions as considered in the first scenario. Again, the fault resistance and fault location are unknown, as the first scenario. In Fig. 4, the relevant sequence network is depicted for the detected fault type (here AG fault).

On the basis of Fig .4, the KVL is carried out for the AG sequence network and the parameters A, B and C are as follows:

$$A = [Z_{34\oplus}.(I_{R23\oplus} + I_{WTG1\oplus}) + Z_{34\ominus}.(I_{R23\ominus} + I_{WTG1\ominus}) + \dots$$
$$\dots + Z_{340}.(I_{R230} + I_{WTG10})] \quad (10)$$

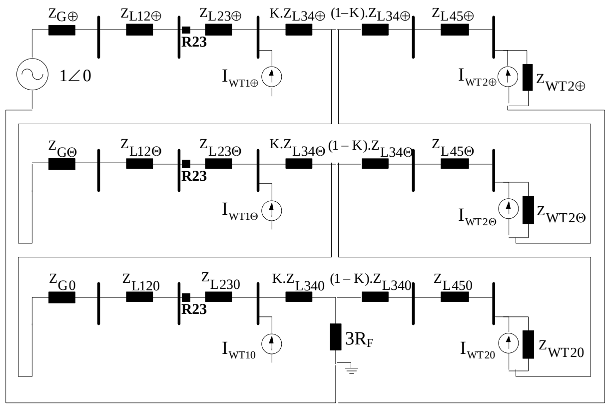


Fig. 4. Sequence network for AG fault condition.

$$B = 3(I_{R230} + I_{WTG10} + I_{WTG20}) \quad (11)$$

$$C = 1\angle 0 - Z_{\oplus}.I_{R23\oplus} + Z_{\ominus}.I_{R23\ominus} + Z_0.I_{R230} \quad (12)$$

$$Z = Z_G + Z_{L12} + Z_{L23} \quad (13)$$

The equations are solved and unknown parameters are calculated as the first case, K with (5) and R_F with (6). Accordingly, the compensation Term I_U is calculated as follows.

$$I_U = \frac{N}{Z_G + Z_{L12} + Z_{L23} + K.Z_{L34} + 3R_F} \quad (14)$$

$$N = Z_{34\oplus}.I_{WTG1\oplus} + Z_{34\ominus}.I_{WTG1\ominus} + Z_{340}.I_{WTG10} + \dots$$
$$\dots + 3R_F.(I_{WTG10} + I_{WTG20}) \quad (15)$$

If the calculated K is negative, then the compensation term is calculated as follows:

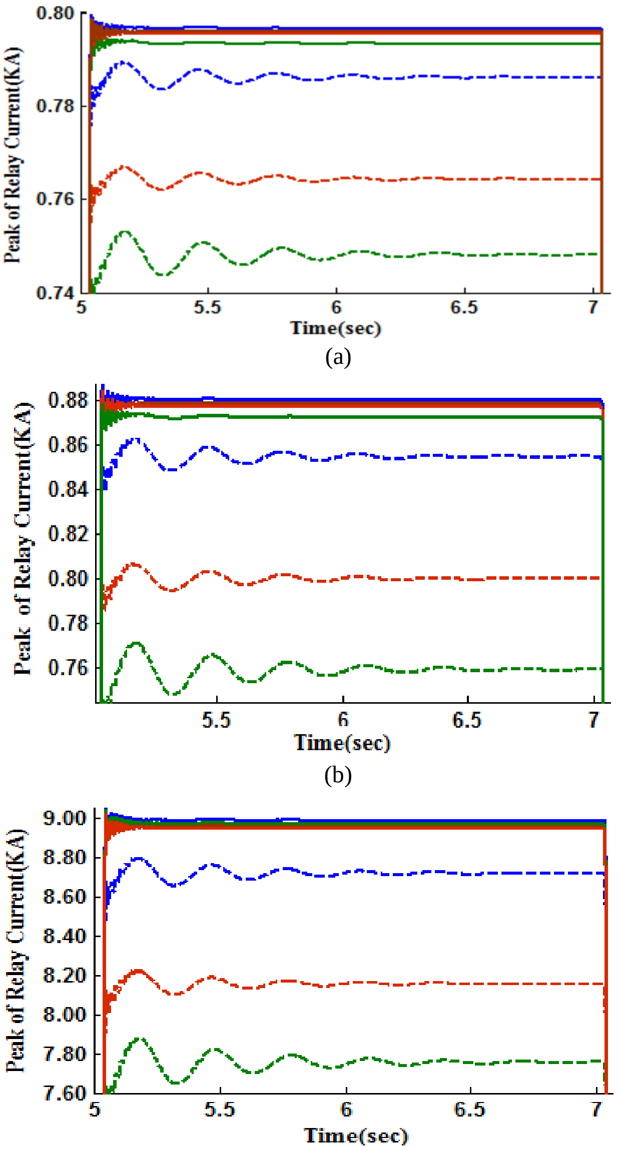
$$I_U = \frac{3R_F.(I_{WT10} + I_{WT20})}{Z_G + Z_{L12} + K.Z_{L23} + 3R_F} \quad (16)$$

Thus, the compensation is calculated and implemented for relay R_{23} seen current. Such a condition is simulated for different condition as in the first scenario for both fault location and DGs conditions. The results are presented in Fig .5. As shown, the DGs impact on current seen by R_{23} increases when DGs increase the generation. Thus the underreach is directly depended to DGs generation condition. Here WT2 is also cause the R_{23} to be underreached. This effect is considered for one case in both scenarios.

It should be mentioned that the fault resistance affects the simplifications considered in the equations and the final results. If the fault resistance rise, then load currents and internal voltage drop of WTGs must be considered which are not considered to simplify the equations already.

CONCLUSION

The most negative effect of DGs on overcurrent protection system of a smart micro-grid, i.e. the relay underreach, was investigated. In this paper, three-phase and single-phase to ground were studied for different fault locations and different level of DGs generation. The relevant equations were obtained and the underreach current seen by relays were compensated through the corrective term. The simulation results show that the proposed method can reliably compensate the DGs underreaching impact for the overcurrent protection system of smart micro-grids.



(a)

(b)

(c)

Fig. 5. Currents seen by R23 for AG fault. Dotted line for uncompensated currents and bolds for compensated. Brown for no DG case, Blue for WT1=0.5MW and WT2=0MW, Red for WT1=2MW and WT2=0MW and finally green for WT1=2MW and WT2=1MW, (a) K=+50%, (b) K=+10% and (c) K=-50%.

REFERENCES

[1] M. Baran and I. El-Markabi, 2004, "Adaptive Over Current Protection for Distribution Feeders with Distributed Generators", *Proceedings Power Systems Conference and Exposition. IEEE PES*, vol.2, 715-719.

[2] H.J. Laaksonen, 2010, " Protection Principles for Future Microgrids ", *IEEE Transactions on Power Electronics* . vol. 25, no. 12, 2910-2918.

[3] I. Xyngi and I. M. Popov, 2010, "Smart Protection in Dutch Medium Voltage Distributed Generation Systems", *Proceeding Innovative Smart Grid Technologies Conference Europe* , 1-8.

[4] K. Mäki, *et al.*, 2005, "Protection issues in planning of distribution network including distributed generation", pp. 1-5.

[5] R. C. Dugan and T. E. McDermott, 2001, "Operating conflicts for distributed generation on distribution systems", *Rural Electric Power Conference*, pp. A3/1-A3/6.

[6] Zeineldin, H.H.; Kirtley, J.L., 2009, "A Simple Technique for Islanding Detection With Negligible Nondetection Zone" *IEEE Transactions on Power Delivery*, vol. 24, no. 2, 779-786.

[7] S. M. Brahma and A. A. Girgis, 2002 "Microprocessor based reclosing to coordinate fuse and recloser in a system with high penetration of distributed generation" *In Power Engineering Society Winter Meeting*, Vol. 1, 435-458.

[8] R.M. Chabanloo, H.A. Abyaneh, A. Agheli and H. Rastegar, 2011, "Overcurrent relays coordination considering transient behavior of fault current limiter and distributed generation in distribution power network" *IET Generation, Transmission & Distribution*, vol. 5, no. 9, pp. 903-911.

[9] R. Jafari, H. Askarian Abyaneh, G. B. Gharehpetian and A. J. Ghanizadeh, 2012, "Multi-Agent Based Fault Location for Smart Micrograds with Distributed Generators", *2nd Iranian Conference on Smart Grids, ICSG 2012, Tehran, Iran*, May 23-24, pp.1-5.

[10] P. Mahat, Zhe Chen, B. Bak-Jensen, C.L. Bak, 2011, "A Simple Adaptive Overcurrent Protection of Distribution Systems With Distributed Generation" *IEEE Transactions on Smart Grid*, vol. 2, no. 3, pp. 428-437.

[11] Ch. L. Chuang ; Y. Ch. Wang ; Ch. H. H ; J. Y. W ; Ch. H. L and Y. T. Hsiao, 2011, "A Hybrid Framework for Fault Detection, classification, and Location—Part I: Concept, Structure, and Methodology" *IEEE Transactions on power delivery*, vol. 26, no. 3, pp. 1988-1998.

BIOGRAPHY

Rahim Jafari was born in Urmia, Iran, in 1988. He received his B.Sc degree in electrical power engineering in 2010 from Tabriz University, Tabriz, Iran. He is currently, pursuing M.Sc in power electrical engineering at Amirkabir University of Technology (AUT), Tehran, Iran. He has many experiences in protection of distribution systems. His research interests include power system protection especially distance protection, wide area protection, distributed generation systems and real time simulation.