SCHOOL OF ELECTRICAL, ELECTRONIC AND COMPUTER ENGINEERING
(EECE)

IMPACT OF DISTRIBUTED GENERATION ON DISTRIBUTION NETWORK PROTECTION

Literature review

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Abstract

The increasing penetration of distributed generation (DG) in power systems creates new challenges and problems for network operators, where it is necessary to investigate many concerning technical, economical and regulatory issues. In terms of physical integration, protection is one of the most important topics. In this research, the interconnection of DG units with power systems is discussed. Also new protection schemes for both distributed generators and utility distribution networks will be developed.

This document is the result of a study of the literature and intends to give an overview of the issues and current situation regarding the protection of DG. The first part gives a basic introduction to distributed generation and power system protection. The second part discusses DG technology and a general overview is presented in section 3. The impact of DG on electric networks is discussed in section 4 and section five examines the impact of DG on protection, after which the proposed work is described in detail. Finally conclusions are presented in section 6.

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Section One

Introduction

The increasing effect of fossil fuel use on the environment has led to more attention to alternative energy sources. Distributed Generation (DG) based on renewable energy technologies is likely to become a more important energy option in future generation systems [1-3]. Distributed Generation (DG) is expected to play an increasingly important role in electric power system infrastructure and market [2]. DG technologies include photovoltaic systems, wind turbines, internal combustion engines, combustion turbines, micro turbines and fuel cells, among others [4].

Defined as the development of a set of sources of electric power connected to the distribution network, or the customer side of the meter, DG implementation in the distribution system has many benefits in both economical and operational terms [2,5].

Integrating generation sources with the distribution networks has many implications concerning operation, maintenance, and planning [6]. Such issues can be considered as significant barriers that may limit the penetration of DG into electrical networks [6]. Over the last decade so much research has investigated the problems of interconnecting DG with electric power systems [1-7]. This project focuses on the detailed the impact of DG on over current protection for radial feeders and distribution transformer.

Section Two

Distributed Generation Technology

2.1 Definitions

Distributed generation is a new relatively concept in the economics literature concering electricity markets, and is a result of the deregulation of the electric power sector [1]. DG has many definitions because it is a new trend in electric power system [7]. Generally speaking, it can be defined as the development of small, modular electric generation systems close to the point of consumption [1,5,7,8]. In the last decade, technological innovations and a changing economic and regulatory environment have resulted in increasing interest in distributed generation [9].

2.2 Distributed Generation Feature

In today's open energy market, distributed energy systems are assuming an increasingly important role. According to Ackerman et al. [5], DG is an electric power source connected directly to the distribution network or on the customer side of the meter. Borbely and Kreider [4] stated that, "Distributed generation is any small-scale electrical power generation technology that provides electric power at or near the load site; it is either interconnected to the distribution system, directly to the customer's facilities, or both". The rating of distributed generation power units has currently used [5] mainly range between a few kilowatts up to 100 MW [1, 5, 7].

Traditionally, electricity is generated in large power stations, located near resources or at logistical optima; it is transported through a high-voltage transmission grid and is locally distributed through medium-voltage distribution grids. DG aims to add deploy flexibility in of energy sources, increase the reliability of supply, and reduce both emissions and the dependence on fossil fuels (Figure 1) [9]. The goals of DG include the minimization of the environmental impacts of energy production and exploiting the benefits of integrating renewable energy sources to electric systems. It can also contribute to the reduction of transmission losses [9].

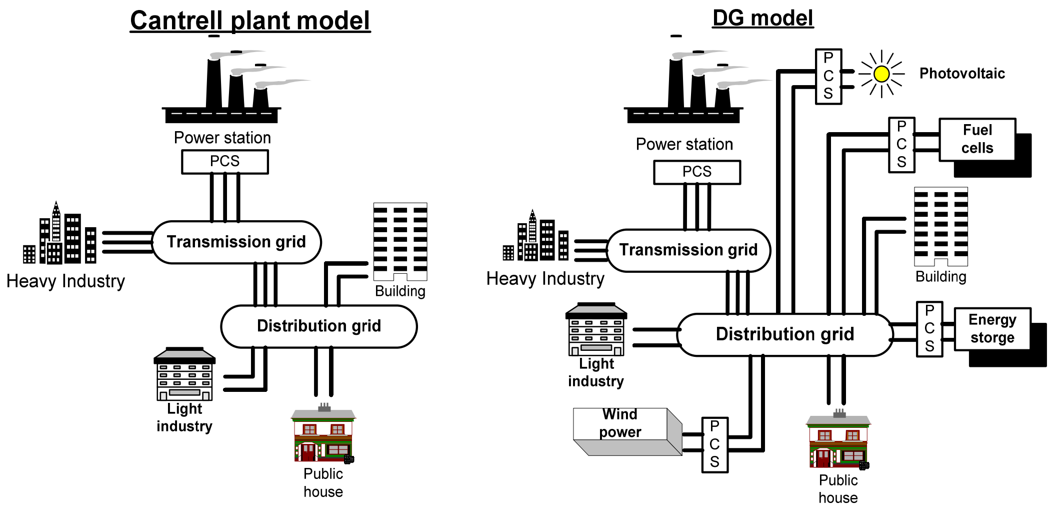


Figure 1: *Schematic diagram of traditional central-plant model and DG-model.*
PCS stands for power conditioning system [9]

Certain DG technologies are not new, such as internal combustion engines and gas turbines. On the other hand, due to changes in the utility industry, several new technologies are being developed or advanced toward commercialization, including fuel cells and photovoltaics [10]. Figure 2, lists different distributed generation technologies, including wind turbines, photovoltaic (PV) systems, micro-turbines, fuel cells, biomass based generators and small hydro plants. These types must be compared to choose the most suitable ones according to the site of placement [4,7].

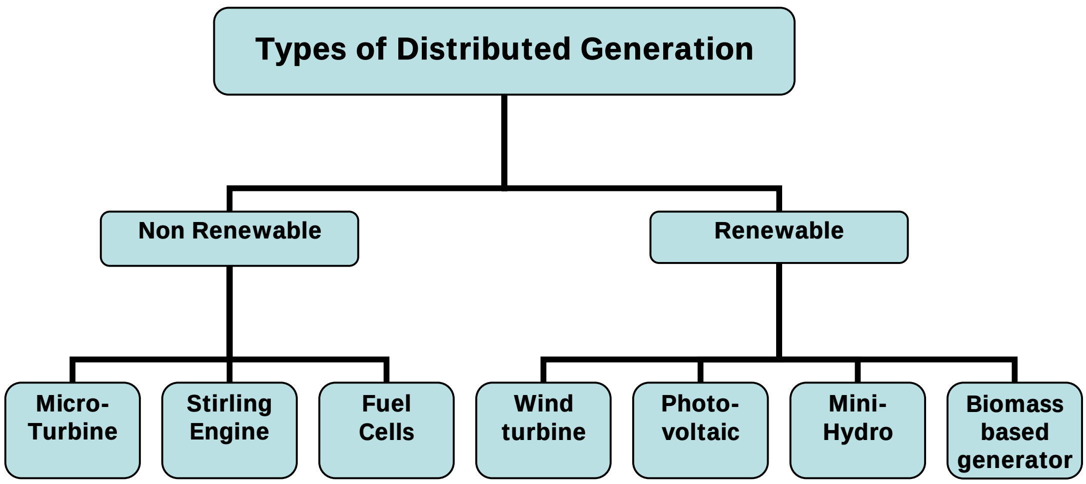


Figure 2: *Distributed generation technologies for power generation*

2.3 The Future of Distributed Generation

Due to the problems caused by climate change, there are great challenges which the international community must face [11]. Renewable energy sources (RES) are one of the most promising means to overcome these problems and cut global carbon emissions. Over the last decade, the EU has put significant effort into developing a common strategy in the energy sector [11]. Many environmental benefits can be achieved with the increasing use of RES for electricity generation [4]. As a consequence, the EU has planned to increase the use of renewable energy [12]. The EU strategy is that 22.1% of the total electricity consumption in 2010 should stem from RES. For example, Greece aims to increase the contribution of RES to an indicative 20.1% (European Directive 2001/77/EC) [13] and it is projected that approximately 20% of all newly installed capacity in Germany will use DG [4].

Furthermore, the rapid growth of distributed electricity generation is foreseen. According to World Energy Outlook (2002), it is expected that annual distributed electricity output will reach 35 GWh by the year 2030 with an annual growth rate of 4.2% between 2000 and 2030 [14]. The use of renewable energy and combined heat and power to limit greenhouse Gas emissions is one of the main drivers of distributed generation [15].

Section Three

General Overview of Traditional Distribution Systems

Electric power distribution is the portion of the power delivery infrastructure that takes electricity from the highly meshed, high-voltage transmission circuits and delivers it to customers [16]. Figure 3 shows the major components of the electric power system [17].

A typical distribution system consists of one or more distribution substations consisting of several transformers and a number of primary distribution feeders emanating from it. The distribution transformer is supplied by the primary distribution feeder and transforms the voltage of the primary feeder to the lower voltage most commonly used by consumers. The secondary lines provide electric service directly to the consumer at the lower voltages produced at the output terminals of the distribution transformers [16].

Primary distribution includes three basic types: (1) radial, (2) loop, (3) and primary network systems [18]. In radial systems the distribution substations feed primary feeders (lines or cables). The loads are connected directly to the feeders through fuses. The system is economical but less reliable. Loop connections are better because they are more economical and fairly reliable. Here the main feeder is supplied from two independent distribution substations which stations share the load. The problem with this connection is the circulating current that occurs when the two supply station voltages are different [17]. The primary network system consists of a grid of interconnected primary feeders supplied from a number of substations. It provides higher service reliability and quality than a radial or loop system. Only a few primary networks are in operation today. They are typically found in downtown areas of large cities with high load densities [18].

The electrical load of a customer is the sum of the load drawn by the customer’s individual appliances. Load levels vary through the day, peaking in the afternoon or early evening.

"The distribution system is operated and controlled using SCADA (system control and distribution automation) at a dispatch center" [19]. The first real deployments of distribution SCADA systems began in the late 1980s and early 1990s. As the market expanded, SCADA vendors who had been providing transmission SCADA began to take notice of the distribution market. The automation of the distribution systems continues to increase. There are many benefits of distribution automation, among which is the ability of the distribution network to manage and control the operation of distributed generation systems [19].

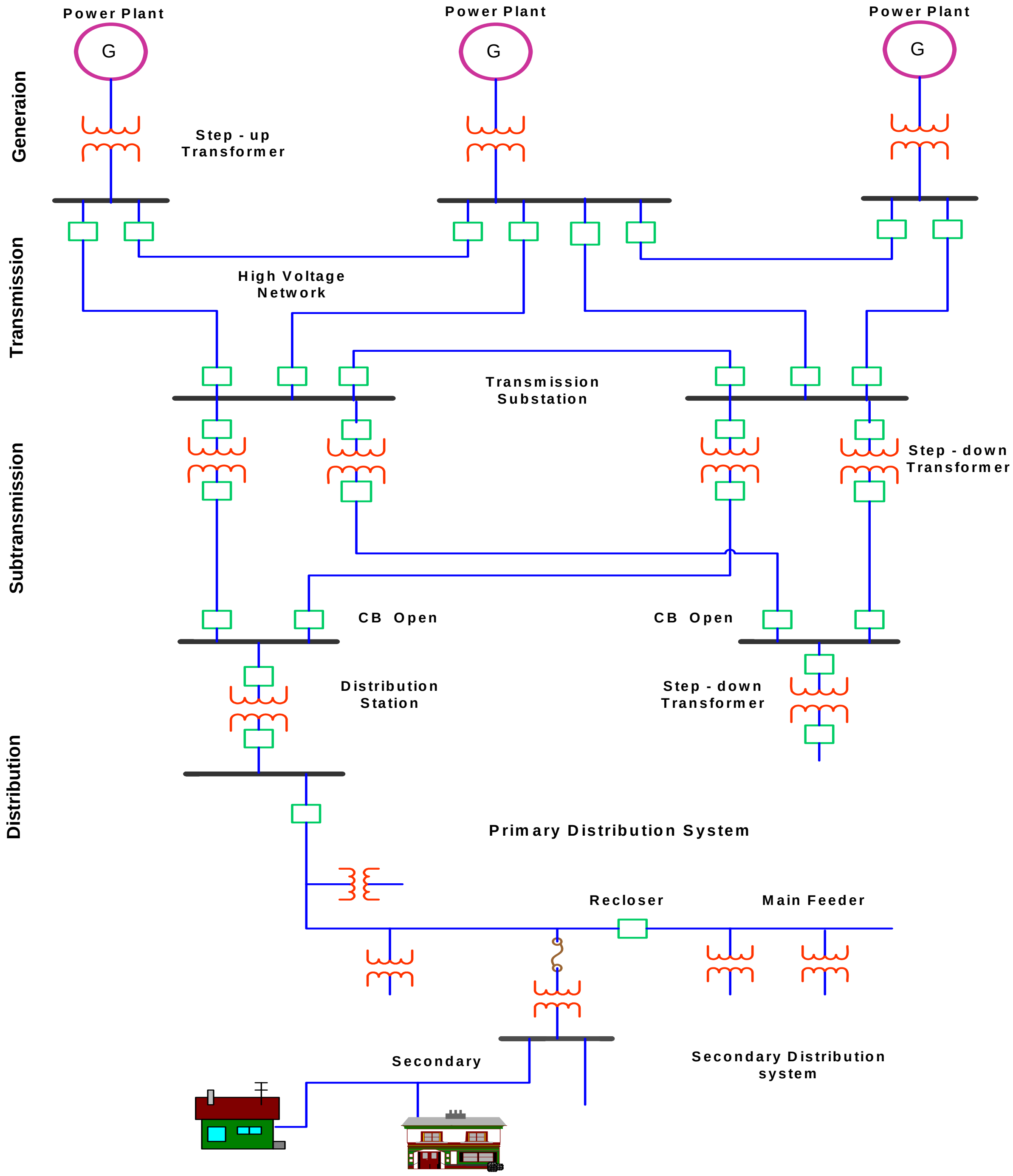


Figure 3: *Major components of the electric power system [19]*

Section Four

Impacts of Distributed Generation on Electric Network

DG has impact various types of on power systems which can be categorized: financial, technical, and regulatory [1-3, 6, 7].

4.1. Financial Cost Impact

One of the key difficulties in the wide spread success of DG is the relatively high capital costs per kW of installed power compared to large central plants [14]. Furthermore, different DG technologies differ from each other in this respect quite considerably [4].

4.2. Technical Impacts

4.2.1 Impact on power quality

The connection of DG might cause over-voltage, power factor, dips, fluctuations, harmonics, and unbalances of system voltage [6]. The variation in power output, along with the virtually inertia-less nature of the power electronic front-ends of some DG technologies such as wind turbines and photovoltaic, might cause voltage fluctuations [7]. The power injection of DG may decrease or increase power losses in the distribution system, depending on penetration and dispersion levels and the DG technology used [20]. Here, the focus on some potential problems.

a) System frequency

DG may cause small deviations in the frequency of the system. Network operators have to keep these within very narrow margins to prevent negative effects on industrial loads and household applications which depend on it [1].

b) Voltage level

There is a significant impact on voltage level due to connecting DG to the distribution network [5]. The voltage rise effect is a key factor that limits the amount of additional DG capacity that can be connected to rural distribution networks [1].

c) Power conditioning

Most DGs produce alternating currents, but unfortunately some produce direct current (PV and fuel cells). Electronic DC-AC inverters have to be used as an interface, which may increase the system harmonics. Similar problems arise with variable wind speed machines [5].

4.2.2. Impacts on power system operation

The connection of DG to the network might have a significant impact on the power flows, voltage profiles, voltage stability, protection selectivity, and power quality for both customers and electricity suppliers [21].

a) Changes in power flow

Overall electrical losses are influenced by changing power flow patterns [1]. Normally, one would assume that losses decrease when generation is brought nearer to the load site. However, a local increase in power flow in low voltage cables with higher resistance and current may have the opposite consequence [22]. The distribution system normally operates in a radial mode. In the case of connecting DG to the grid, power flow will be more complex in terms of bidirectional power flows [3].

b) Protection

A number of different aspects of DG protection can be identified, all of which are important and need to be carefully addressed when connecting DG to distribution networks [23]. Section 5 discusses the impact of DG on distribution network protection.

c) Stability

Distribution networks were long considered as passive parts of the system which remained stable under most design circumstances, so that issues of stability did not need be considered. With the increasing penetration of DG in distribution networks, its significance for network security becomes greater. Several new issues have to be considered, such as transient (first swing) stability as well as long term dynamic stability and voltage collapse [3].

d) Voltage regulation

One of the main purposes of system operation is to supply customers at a voltage which is within a prescribed range, maintaining the entire network in a stable and reliable state. Increasing DG penetration has an observable impact on voltage regulation [6], [24].

4.2.3. Energy security

Energy security is interpreted in some studies [25] as the reliability of the electricity system. IEA (2002) stated that distributed generation can contribute to reducing the risks and costs of blackouts [14]. DG is seen tool helping to reduce the private costs and risks for electricity customers of system failures [1].

4.3. Regulatory Impact

As with any new technique, DG systems requires a clear policy and associated regulatory instruments. Improvements in the regulatory framework for electricity networks could help to overcome most present barriers and lead to a growth in electricity supplied from distributed generation [26].

Section Five

Impact of Distributed Generation on Distribution Network Protection

5.1 Protection Issues with DG

The Integration of DG to distribution networks may impact on the network protection system [27-35]. The overall problem when integrating DG on existing networks is that distribution systems are unidirectional systems from central generation downstream to the consumer.

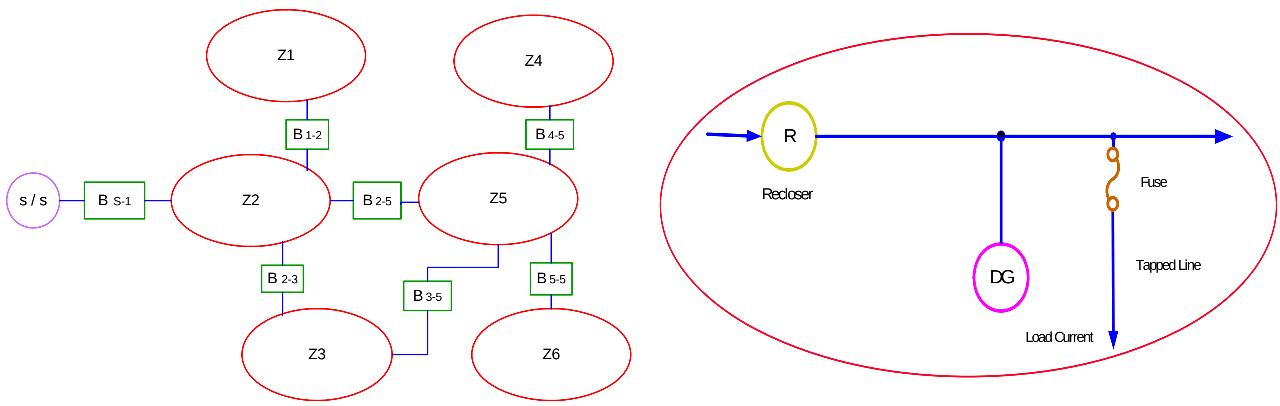
Conventional protection systems were designed in common medium voltage and low voltage level distribution networks in a passive paradigm; i.e. where no generation is expected in the network. In future distribution systems, the networks will be more active and conventional protection methods are unsuitable [27].

As a result, the additional fault current supplied by DG can cause relays to under-reach or overreach [28]. Girgis and Brahma have explored "the effect of DG on protective device coordination such as fuse-fuse, fuse-recloser and relay-relay, depending on size and placement of DG". They concluded that problems related to protection devices and coordination schemes require a special attention since the reliability of the system maybe weakened [28].

The distribution network is primarily composed of radial feeders designed for unidirectional power flow. The interconnection of DG in radial distribution systems presents situations not normally encountered by the distribution engineer. Doyle [29] pointed out some of the more common problems and the resulting misapplication of protection schemes upon the installation of DG. He discussed the impacts of DG on system protection and coordination particularly in cases where DG is added to a distribution feeder with existing line reclosers and fuses.

An IEEE report [24] they investigated various protection issues including "protective device coordination problems due to infeed and bi-directional current flow; effects on synchronizing and autoreclosing; the potential for forming small islanded systems; and issues related to ground fault detection". The authors concluded that the addition of DGs to a distribution system has a great effect on relay systems, which are traditionally designed for radial operation.

Sukumar et al [30] suggested an adaptive protection scheme to investigate the effect of high DG penetration on protective devices coordination. They explored the effect of the size, type, and placement of DG on device coordination. The approach was based on dividing the distribution system into zones as shown by (Figure 4) [30], each zone composed of both DG and load, with DG capacity being a little more than the load. The zones are separated by breakers connected to a main relay located in the substation. The main relay would sense any fault, and detect both the type and location of the fault, then isolate the faulted zone by tripping appropriate breakers and DG connected to this zone. Results of implementation of their proposal scheme on a simulated actual distribution feeder are reported [30].



a- Protective zones b- Main Components of each zone

Figure 4: *Distribution system divided in breaker-separated zones* [30].

Jager et al [31] showed that "new protection grading principles which reduce the fault clearing times ensuring selectivity nevertheless". They investigated ring networks with numerous DG units and radial networks, concluding that the use of inverse time characteristics can lead to significantly shorter delay times while simultaneously ensuring selectivity.

Maki et al [32] investigated the effects of DG on the feeder protection of a distribution network in a ring operation mode.

Freitas et al [33] presented "a detailed investigation on the performance characteristics of vector surge relays used to detect islanding of DGs". Computer simulations were used to obtain the performance curves of the relay.

kashem and Ledwich [34] studied the impact of the inclusion small DG of units existing protection systems with single wire earth return lines (usually constructed in rural areas to supply electricity to remotely located customers). DG sensitivity during faults was also explored, and it was concluded that, for single wire earth return lines, there would be no effect of DG inclusion on system sensitivity and existing protection

Salman and Rida [35] reported "an investigation to determine the impact of the integration of DGs on the settings of protective devices of electrical feeders emanated from the substation to which DGs are connected". Their study concluded that there is a significant effect of DG on the clearing time of protective devices installed at distribution feeders.

Such research into the impact of DG on network protection has thus highlighted many issues arise, system protection issues. The present study will focus on the over-current protection of radial line and distribution transformers in the DG environment.

4.2 Proposed Work

The Protection of three phase distribution transformers in radial distribution systems using fuses is considered to be a classical protection system. It is general practice to install an internal or external fuse on the incoming side of each distribution transformer [36]. Figure 5 shows the distribution feeder with distribution transformer and fuses [36]

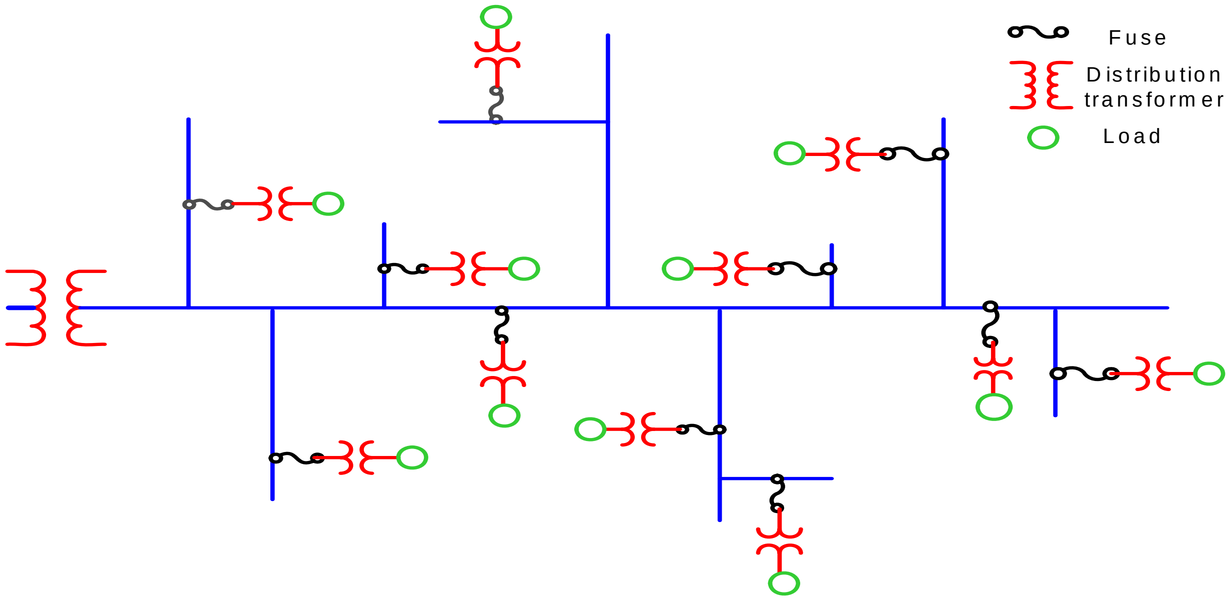


Figure 5: *Classical distribution system* [36]

The correct protection of distribution transformers against overload and short circuits has an essential influence on consumers supply continuity and safety of people. Many years of domestic maintenance experience proves that the cheapest as well as most effective protection of distributions transformer protection against the results of overloads and short circuits are properly selected fuses [34]. The rated current and breaking capacity of a fuse are selected according to basic rules taking into consideration permissible transformer overloads or the maximum rating of the transformer. Fuse selection and the method of protection distribution transformers on the low voltage side depend mainly on the nominal transformer power loss on fuse type or prospective short circuit current on the high voltage side [36]. Nowadays the nature of distribution systems is, however, changing due to the addition of generating units to the distribution network.

Integrating DG with traditional distribution systems leads to the need for studying fuse-fuse and recloser fuse coordination to show the suitability of this classical protection to the system.

A detailed study of this subject will be undertaken, focusing on the over current protection of radial lines and distribution transformer in the distributed generation (DG) environment, starting with the classical protection system using fuses. Then a system model will be tested with and without DG in order develop a strategy to deal with the new system by either replacing the old protection system and redesigning it or retaining the old system with modifications. The research process to be used is as follows:

- Studying the over current protection of radial lines and distribution transformer in the classical form using fuses.
- Modeling the system using MATLAB SIMULINK software.
- Simulating the system without DG and designing fuses for radial line and transformer protection.
- Simulating the system with DG and with the previously selected fuses.
- Comparing the results, drawing conclusions, and making recommendations.

Section Six

Conclusion

A distributed generation unit can be considered as a set of dispersed generators connected to the customer side of the distribution system. Distributed generation may have a significant impact on the system and the operation of equipment in terms of steady-state and dynamic operation, reliability, power quality, stability and safety for both customers and electricity suppliers. This impact may manifest itself either positively or negatively, depending on the distribution system, DG and load characteristics. Integrating DG with classical distribution systems leads to the need to study the protection of the distribution transformer fuse co-ordination to show the suitability of classical protection methods. DG fuse co-ordination for a radial distribution system will be explored in this study.

References

[1] Pepermans, G., Driesen, J., Haeseldonckx, D., Belmans, R., D'Haeseleer, W., "Distributed Generation: Definition, Benefits and Issues", *Energy Policy*, Vol.33, No.6, Ref. JEP01382, 2005; pp. 787-798.

[2] Bendel C., Nestle D., "Decentralized Electrical Power Generators in the Low Voltage Grid– Development of a Technical and Economical Integration Strategy", *International Journal of Distributed Energy Resources,* Vol. 1, No. 1, 2005; pp.63-70.

[3] Pecas Lopes, J.A.., Hatziargyriou, N., Mutale, J., Djapic, P., Jenkins, N., "Integrating Distributed Generation Into Electric Power Systems: A Review of Drivers, Challenges And Opportunities", *Electric Power Systems Research*, Vol.77, 2007; pp.1189–1203.

[4] Borbely, A.-M., Kreider, J.F., *"Distributed Generation, The Power Paradigm for the New Millennium",* CRC Press LLC, 2001; pp.1-49.

[5] Ackermann, T., Andersson, G., Soder, L., "Distributed Generation: a Definition", *Electric Power Systems Research,* Vol. 57, 2001; pp. 195-204.

[6] "*DG Power Quality, Protection and Reliability Case Studies Report*", GE Corporate Research and Development, National Renewable Energy Laboratory. Subcontractor report, NREL/SR-560-34635, August 2003.

[7] El-Khattam, W., Salama, M.M.A., "Distributed Generation Technologies, Definitions and Benefits", *Electric Power Systems Research,* VOL. 71, 2004; pp.119–128.

[8] Zareipour, H., Bhattacharya, K., Canizares, C.A., "Distributed Generation: Current Status and Challenges", *Proc North American Power Symposium* (NAPS), Moscow, Idaho, 2004; pp. 392-399.

[9] Hartikainen, T., Mikkonen, R., Lehtonen, J., "Environmental Advantages of Superconducting Devices in Distributed Eelectricity-Generation", *Applied Energy,* Vol. 84, 2007; pp. 29-38.

[10] Poullikkas, A., "Implementation of Distributed Generation Technologies in Isolated Power Systems", *Renewable and Sustainable Energy Reviews*, Vol. 11, 2007; pp. 30-56.

[11] Tegou, L-I., Polatidis, H., Haralambopoulos, D.A.," Distributed Generation with Renewable Energy Systems: The Spatial Dimension for an Autonomous Grid", *proceedings of the 47th Conference of the European Regional Science Association*, ERSA 2007, Paris, France, August 2007. Available online at: http://sadapt.inapg,inra..fr/ersa2007/papers/728.pdf

[12] Krewitt W., Nitsch J. "The Potential for Electricity Generation from on-Shore Wind Energy Under the Constraints of Nature Conservation: A Case Study for Two Regions in Germany", *Renewable Energy*, Vol.28, 2003; pp. 1645-1655.

[13] Official Journal of the European Communities, "*On the Promotion of Electricity Produced From Renewable Energy Sources in the Internal Electricity Market*" Directive 2001/77/Ec of The European Parliament And of The Council of 27 September 2001. Available online at: http://faolex.fao.org/docs/pdf/eur40867.pdf

[14] International Energy Agency, *World Energy Outlook 2002*, OECD/IEA 2002.

[15] Soderman, J., Pettersson, F., "Structural and Operational Optimization of Distributed Energy Systems", *Applied Thermal Engineering*, Vol. 26, 2006; pp.1400- 1408.

[16] Short, T.A., "Electric Power Distribution Handbook", CRC Press LLC, 2004; pp.1-31.

[17] Dorf, R.C.,"The Electrical Engineering Handbook", CRC Press LLC, 2000, chapter 65.

[18] Casazza, J.Delea, F., "Understanding Electric Power Systems: An Overview of the Technology and the Marketplace", John Wiley & Sons, Inc., 2003; pp.85-97.

[19] Grigsby, L.L., "Electric Power Engineering Handbook", Taylor & Francis Group, 2006.

[20] Nagpal, M., Plumptre, F., Fulton, R., and .Martinich, T.G., "Dispersed Generation Interconnection—Utility Perspective", *IEEE Transactions on Industry Applications*, Vol. 42, No. 3, May/June 2006 ; pp.864-872.

[21] Vu Van, T.,Woyte, A., Soens, J., Driesen, J., Belmans, R., "Impacts of Distributed Generation on Distribution System Power Quality", *Proceedings of Electrical Power Quality Utilisation*, Cracow, Poland, September 2003; pp.585-591.

[22] Dondi, P., Bayoumi, D., Haederli, C., Julian, D., Suter, M., "Network Integration of Distributed Power Generation", *Journal of Power Sources*, Vol. 106, 2002, pp. 1–9.

[23] Chernoff, H., Lorand, R., “The Impact of Distributed Generation on Local Distribution Companies”, Report submitted to American Gas Association, Washington, DC, March 17, 2000.

[24] Seegers, T., “Impact of Distributed Resources on Distribution Relay Protection”, Report by working group D3 to the Line Protection Subcommittee of the Power System Relay Committee of The IEEE Power Engineering Society, January 2003.

[25] Pritchard, R., Hogan, L., “Energy Security in APEC: Assessing The Cost of Energy Supply Disruptions and The Impacts of Alternative Energy Supply Strategies - An Overview”, Report presented to the APEC Energy Working Group, June 2005, available from http:// www.abareconomics.com/publications_html/energy/energy_05/nrg_security.pdf

[26] Ropenus, S., Skytte, K., **“**Regulatory Review and Barriers for the Electricity Supply System for Distributed Generation in EU-15”**,** *International Conference on Future Power Systems,* 16-18 Nov. 2005; pp.1-6.

[27] Ackermann T. and Knyazkin,.V., “Interaction Between Distributed Generation and the Distribution Network: Operation Aspects” *,Proceedings of IEEE/PES Transmission and Distribution Conference and Exhibition Asia Pacific,* Vol. 2, 2002; pp.1357-1362.

[28] Girgis A. and Brahma, S., “Effect Of Distributed Generation on Protective Device Coordination in Distribution System”, *Proc. Large Engineering Systems Conference,* Halifax, NS, Canada, 2001; pp. 11-13.

[29] Doyle M.T., “Reviewing the Impacts of Distributed Generation on Distribution System Protection”, *Proc. IEEE Power Engineering Society Summer Meeting,* Vol. 1, 2002; pp. 103-105.

[30] Sukumar, M., Brahma, A., Girgis, A., “Development of Adaptive Protection Scheme for Distribution Systems With High Penetration of Distributed Generation”, *IEEE Transactions on Power Delivery,* Vol. 19, No. 1, Jan. 2004; pp.56-63

[31] Jäger, J., Keil, T., Shang, L., Krebs, R., “New Protection Co-Ordination Methods in The Presence of Distributed Generation”, *8th International Conference on Developments in Power System Protection,* Amsterdam, 5.-8. April 2004; pp.173-176

[32] Mäki, K., Repo, S., Järventausta, P., "Protection Issues Related to Distributed Generation in A Distribution Network Using Ring Operation Mode", *Nordic Wind Power Conference*, Chalmers University Of Technology, 1-2 March, 2004.

[33] Freitas, W., Xu, W., Huang, Z., Vieira, J.C.M., "Characteristics of Vector Surge Relays for Distributed Synchronous Generator Protection", *Electric Power Systems Research*, Vol. 77, 2007; pp. 170–180.

[34] Kashem, M.A., Ledwich, G., "Impact of Distributed Generation on Protection of Single Wire Earth Return Lines", *Electric Power Systems Research*, Vol. 62, 2002; pp.67-80.

[35] Salman, S.K. and Rida, I. M., "Investigating the Impact of Embedded Generation on Relay Settings of Utilities' Electrical Feeders", *IEEE Transactions on Power Delivery,* Vol. 16, No. 2, April 2001; pp.246-251.

[36] Fink, D.G., Beaty, H.W., "Standard Handbook for Electrical Engineers", McGraw-Hill, 2006, chapter 18.