Use of Neutral Overvoltage Relay for Protection of Industrial Systems with DYN Transformer Operation in Intentional Island

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Abstract. *This article briefly reviews the importance of distributed photovoltaic generation systems in industry and heir growing trend. It also addresses the problem of islanding in such systems and proposes an alternative for protecting power systems in the event of phase-to-ground faults in the ungrounded feeder during islanding using the neutral overvoltage relay. The 59N function of the relay eliminates the need for grounding transformers and prevents the power system from injecting phase-to-ground faults. This avoids potential catastrophic damage to equipment and personnel in the plant, as well as possible loss of profit. The study suggests that the use of the 59N function is a simple and cost-effective solution for photovoltaic generator ground-fault protection that provides greater safety during islanding operations.*
Index Terms: Photovoltaic Distributed Generation, Intentional Islanding, Ground Fault Protection.

1. INTRODUCTION

Industrial economy is characterized by a race among competitors, making cost reduction an increasingly important task in industries. The cost of electrical energy has a relevant impact on various industrial sectors. Considering the hydrological issues in Brazil that led to the creation of market flags in the electricity tariff in 2015, coupled with the possibility of reducing the cost of energy generation through photovoltaic sources, there is a growing trend in the implementation of photovoltaic power plants in industries (ANEEL, 2023).

Distributed photovoltaic generation can be used in parallel with the grid (on-grid systems), completely disconnected from the grid (off-grid systems), or a combination of both (hybrid systems). When hybrid systems with high power capacity are used, the topology of the system resembles large power plants with synchronous generators in terms of the need for a transformer to connect to the distribution grid. When the system is isolated, this transformer becomes an ungrounded feeder, leaving part of the system without an earth pull and requiring additional measures to protect against phase-to ground faults, since without an earth pull, no zero-sequence current circulates and thus no overcurrent relays are tripped.

This study addresses the use of the neutral surge relay as an alternative to the use of grounding transformers to protect the ungrounded feeder (when generation is isolated) to prevent the system from injecting a phase-to-ground fault that can cause severe damage to people and equipment.

2. DISTRIBUTED PHOTOVOLTAIC GENERATION IN INDUSTRIES

Energy utilization is one of the main marks of financial turn of events and the degree of life quality in any region. It reflects the pace of industrial, commercial and service activities. In Brazil, the industrial sector is the second largest consumer, accounting for approximately 32.3% of energy consumption (ANEEL, 2023).

As one of the largest consumer of energy, the industrial sector also has significant potential to harm the environment, either through the production process or through the manufacture of environmentally harmful products. Recognizing the environmental impact, industries have begun to focus on sustainable development and energy efficiency measures (Tonim, 2009).

Distributed generation (DG) is emerging as an alternative that is not only more attractive in the energy transmission configuration, bringing the generation and consumption of energy much closer together, thereby deferring investment in infrastructure development, but also as an ally in reducing losses associated with energy transport, leading to low environmental impact and diversification of the energy matrix (ANEEL, 2014).

In the context of DG, photovoltaic stands out as an energy source that has experienced an exponential growth in its installed capacity in recent years, representing 5.5% of the installed capacity of the Brazilian electricity matrix and playing an increasingly important role in this matrix (MME, 2019).

In addition to the decreasing cost of photovoltaic energy generation, there were also hydrological problems in the past decade that led to an increase in electricity tariffs and gave a price to the flags for electricity usage in 2015, affecting all captive consumers connected to the National Interconnected System (ANEEL, 2021).

According to the International Energy Agency, solar energy is expected to grow by about 630 GW per year until 2030 to achieve carbon neutrality targets (IEA, 2021). In this context, a movement has begun towards the implementation of small scale plants in industry, where 58% of the energy matrix is renewable (MME, 2019). The high power and energy requirements make the installation of these plants slow and complex. Therefore, studies have been carried out to optimize the use of photovoltaics in industry.

In 2015, was proposed a tool to study the economic feasibility of implementing photovoltaic systems in industry, based on the normative resolution No. 482/2012 of ANEEL, which establishes the general conditions for access to micro and mini energy production. With this tool, managers would have an optimized decision-making process for the implementation of the system (Hobmeir, 2015).

A study analyzed the feasibility of introducing DG with energy storage at a container handling facility in Salvador, Bahia. Two proposals were made, the first being an off-grid power plant, i.e., a power plant disconnected from the distribution grid and covering only peak consumption. The second proposal was a hybrid power plant that covers peak consumption and injects excess energy into the grid, generating energy credits for compensation (Cardoso, 2021).

A case study was conducted in a textile company in Minas Gerais to analyze energy efficiency through analysis and site visits. The introduction of energy efficiency indicators was proposed to better control the cost-benefit ratio of the electricity consumed. Following the company culture, the introduction of the eco-efficiency model was proposed, along with the installation of an in-house photovoltaic solar power plant to meet the factory's electricity needs in a clean, renewable and economically viable way (Torre, Alves, Correa, 2018).

In an aluminum derivatives industry, a study was conducted for the implementation of DG system. Based on the system design and technical and economic feasibility analysis, the implementation of the system was deemed viable (Pilati, 2018).

3. PROTECTION OF ELECTRICAL POWER SYSTEMS ON INTENTIONAL ISLAND

3.3 Grounding System

Historically, there was a tendency for electrical systems to be ungrounded. Around the 1940s, a significant number of motor insulation failures were observed due to intermittent ground faults. As a result, many systems started to be grounded, typically solidly grounded at the delta vertex (Bernardi, 2015).

In new projects, the simple specification of delta-star transformers instead of delta-delta gradually led to grounded star systems with grounded neutral. As for ground-fault protection, transformer specifications required the neutral to be accessible on the star side through an insulating bushing. The grounded star-delta (wye) connection is a common transformer configuration used in electrical power distribution systems. In this configuration, the primary winding forms a delta shape while the secondary winding is connected and grounded in a star shape. This configuration offers advantages such as the elimination of third harmonics due to the delta connection, the maintenance of neutral stability due to the star connection, and protection against ground faults due to the grounding of the secondary winding. The choice of grounded delta-star configuration depends on the specific installation requirements and system conditions, and ensures efficient and reliable power distribution (IEEE, 2010).

Brazilian standards NBR 5410 and NBR 14039, which regulate low-voltage and medium-voltage installations, respectively, define the possible grounding schemes. The grounding schemes should be chosen according to the specifics of each installation.

In Brazil, some utilities require that transformers be grounded at the feed point in the star-delta. One of the reasons for using the delta connection is that the distributed generator will not contribute to the fault current if there is a short circuit between phase and ground in the distribution network (Sguacábia, 2015).

3.4 Islanding of Electrical Power Systems

An island is defined as a condition in which a portion of an area in the power system is supplied with power only by one or more local feeders through their associated common coupling points, while that portion of the area is electrically isolated from the rest of the power system (IEEE, 2018).

The formation of islanding can be of two types: unintentional, when the distribution system interrupts the power supply regardless of the reason, or intentional, when the user deliberately decides or is required to perform this maneuver.

Currently, the protection devices at the point of connection of the distributed generator to the grid are set to avoid unintentional or intentional islanding. ANEEL (Brazil's National Electric Energy Agency) advocates islanding of generators and establishes the obligations of both the utility and the generator to ensure the safe and proper operation of the system (ANEEL, 2014).

When islanding occurs in systems whose protection system includes delta-star feeders, in addition to other protection problems such as loss of selectivity and sensitivity, grounding is lost because the grounding reference (utility substation) is interrupted. This is due to the lack of circulation of the zero sequence current on the delta side.

Zero sequence current is the current that flows in a system when a phase-to-ground fault occurs. This current is characteristic of grounded systems and is responsible for providing a path for the phase-to-ground fault protection to operate. However, in the delta-star feeder, the delta side does not have an effective path for the circulation of the zero-sequence current because the star connection on the secondary side is grounded (Sguacábia, 2015).

This means that in the case of islanding, the delta side of the transformer is not able to detect a phase-to-ground fault, and consequently the phase-to-ground fault protection is not sensitized. This loss of sensitivity can lead to protection problems and a higher risk of damage to equipment and people in the isolated system. In the field of intentional islanding, one significant challenge is wellknown - the loss of conservation coordination. Consequently, the research landscape has seen a growing wave of publications focusing on the protection of electrical systems with this characteristic (Allahdadi, Sadeghkhani, Fani, 2020) (Sati, Azzouz, Shaaban, 2023) (Lima et al., 2020) .

3.5 Protection Function 59N

Neutral overvoltage relays, ANSI 59N, are relays that operate in the event of a phase-to-ground fault when the voltage exceeds a predetermined value. They are most often used in ungrounded systems because they allow the detection and elimination of ground faults.

In practice, this relay is used in the secondary of potential transformers (PTs) connected in open star-star ground delta configurations, or by using firmware resources where the displacement voltage is calculated from the phase voltages.

Typical settings are made to coordinate with overcurrent relays, with time-delayed protection set to Vpickup of 110% of rated voltage with a time delay T=3s and Vpickup of 115% of rated voltage with a time delay T=2s (Mardegan, 2020).

3.6 The use of function 59N for ground fault protection

The use of grounded star-delta transformers is widespread in distribution systems. The reason is the elimination of third harmonic voltages by the circulation of third harmonic currents in the delta secondary and the stability of the primary neutral through the delta secondary.

Grounding transformers are used for this type of application is necessary because the grounding transformer would sensitize the protection in the event of a ground fault. In cases where selectivity is not relevant, i.e. the protection could trip the entire bus, the use of function 59N is sufficient (Silva, 2017).

The implementation of the 59N protection must be analyzed to be coordinated with the other protections in both the non islanded and islanded conditions. Recent studies indicate that the overcurrent protection devices should change in the event of islanding, resulting in a change in the relay setting group. However, changing the time delay curve of the relay would not conflict with the 59N setting because the 59N function pickup time is much longer than the typical operating times of overcurrent protection devices (Sguacábia, 2015) (Allahdadi, Sadeghkhani, Fani, 2020) (Mendes, 2018).

4. SIMULATION

In this way, a simulation study was conducted in Simulink to investigate the effects of islanding on ground fault protection in power distribution systems with delta-star transformer configurations. A representative electrical system was set up with a phase-to-ground fault downstream of the generator-transformer in high voltage, as shown in Figure.1.

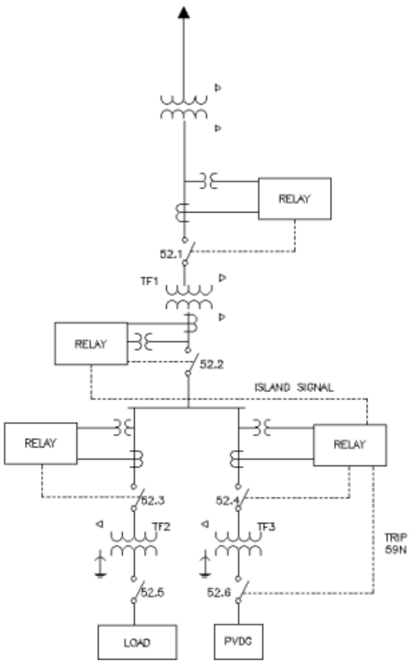

Figure 1 - Typical Simplified Single-Line Diagram.

The system, modeled in Simulink, is an electrical distribution system that involves the operation of several major components. The consumer is represented by an inductive load of 500kVA/PF 0.98 lag, connected to the input SE through a 700 kVA Dyn 13.8/0.48 kV, impedance 5%. A 500 kVA FV DG is also connected to the input bus, through an identical transformer. The consumer is tied to the main grid by a 3 MVA Dyn 33/13.8 kV, impedance 9%. The main grid is composed by a 6 MVA 138 / 33 kV, Dd connection, impedance 11%. To ensure protection and control of the system, circuit breakers have been installed at strategic points downstream of each transformer. Each circuit breaker has an extremely low resistance of 1 micro-ohm, which allows rapid interruption of power in the event of an overload or system failure.The simulation, which was performed discretely with a time interval of 10 microseconds, includes both the behavior of the transformers and the operation of the circuit breakers, providing a comprehensive and accurate analysis of the electrical system. Electrical paramenters of the simulated system are give in table 1, whereas simulation settings are presented in table 2.

Table 1 – Electrical Distribution System DAT.

Transformer	**Capacity (MVA)**	**Voltage Ratio**	**Impedance** (Ω)
1	6	138 kV to 33 kV	11% delta-delta
2	3	33 kV to 13.8 kV	9% delta-delta
3	0.7	13.8 kV to 480 V	5% delta-star
4	0.7	13.8 kV to 480 V	5% delta-star
PVGD	**0.5 (MW)**	**480 V**	**100** ($\mu\Omega$)
Load	**0.5 (MVA)**	**480 V**	**1.04** (Ω)

Table 2 – Simulation Model Settings.

Setting	**Value**
Sampling Interval	1e-5 seconds
Maximum Step Time	1e-6
Maximum Tolerance	1e-6
Jacobian Solver	Automatic
Solver	Variable Step
Electrical System Frequency	60 Hz

5. RESULTS AND DISCUSSIONS

The simulation results show the current and voltage at a given point in the system, shown in the top and bottom sections of figure.2, respectively. The distributed generation is introduced into the system at 0.1 seconds, and the phase-to ground fault occurs at 0.2 seconds and ends at 0.3 second. The simulation adhered to the guidelines of IEEE Std 1547 to ensure a standardized evaluation (IEEE, 2018).

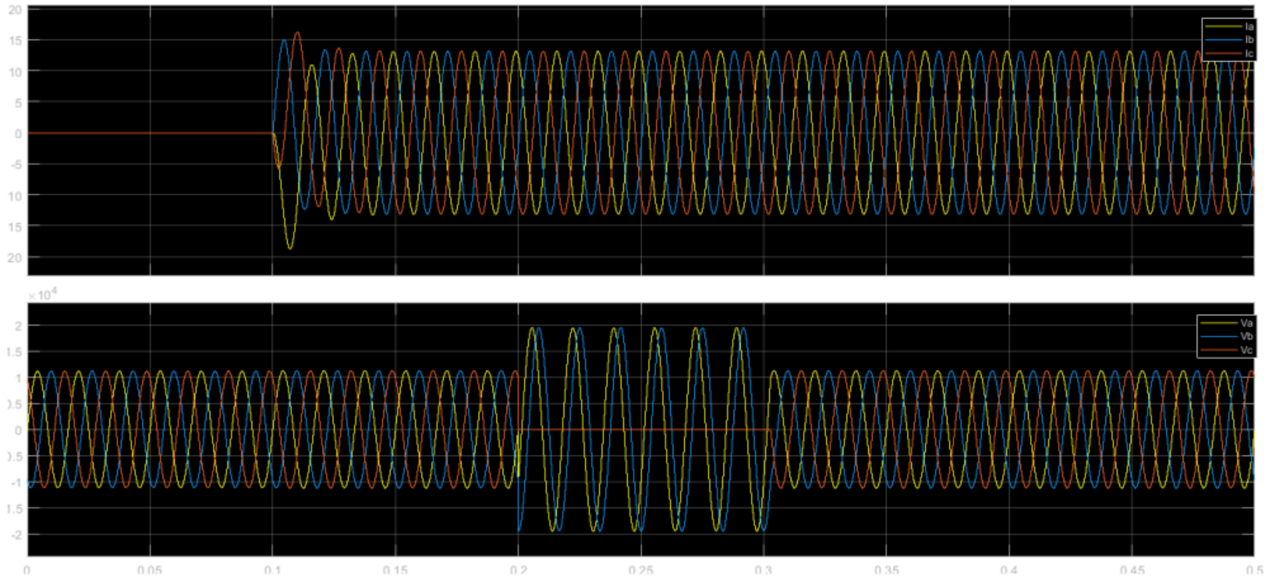

Figure 2 - Simulation showing voltage and current with earth fault.

To address this problem, it is common to use grounding transformers to reestablish the path for zero-sequence current on the delta side. This way, the phase-to-ground fault protection can function properly even during islanding, ensuring the safety and proper operation of the electrical system (Arvizu, Messina, 2016).

In photovoltaic power plants, the generation is always done with low voltage, so the transformers connected to it are grounded and the high voltage side is connected in delta. In case of islanding, the high voltage busbar loses its ground reference, preventing the operation of functions 50/51 and 50/51N, which justifies the use of protection 59N for phase to-ground faults on the high voltage side. When the 59N function is activated, the circuit breaker that connects the power generation to the system is turned off, preventing the equipment from continuing to supply the fault.

In industries with installed power between 500kVA and 5MVA operating in a non-islanded state, typical protection settings include: Shutdown element, interrupting element, coupling transformer, underfrequency and overfrequency protection, current unbalance protection, voltage unbalance protection, directional overcurrent protection and overcurrent protection with voltage limitation. Of the required protections, which would operate in the event of a ground fault is examined, and their typical operating times are reviewed to ensure coordination with the 59N function.

This study also tested hypotheses about the use of the 59N relay as short-circuit protection. Short-circuit resistances from 0.01 ohms to 100,000 ohms were tested, and throughout this range, as expected, the voltage exceeded

115% of the rated voltage, sensitizing the protection device. In addition, the hypothesis of using it for two-phase short circuits was also investigated. Despite the voltage sensitivity of the 59N relay exceeding 115% of the rated voltage, it is assumed that the use of the 50N relay is more suitable due to the current sensitivity.

6. CONCLUSION

This paper conducted a brief survey with the purpose of demonstrating the relevance of photovoltaic distributed neration systems in industries and their growth trend. Additionally, it addressed islanding in this type of system and one of its issues.

An alternative was proposed for protecting phase-to-ground faults of part of the delta-fed system when it is islanded, using the neutral overvoltage relay, which eliminates the need for grounding transformers.

When analyzing possible ground faults in the system presented in Fig.2, the following observations can be made: if the fault occurs on the delta side during islanding, the overcurrent protection would not be sensitive and would not act at 59N. However, if the fault occurs during non-islanding, the overcurrent protection would be sensitive since there would be a reference to ground. In the case of a fault on the delta side, regardless of islanding, it is expected that the generation's overcurrent protection, even with a trip of 59N, would be less selective while maintaining coordination.

It was concluded that the use of the 59N function is a simple and cost-effective alternative for protecting phase-to ground faults in photovoltaic generators with the possibility of islanding, preventing the system from operating with faults, avoiding catastrophic damage to equipment and people in the building, as well as potential loss of profits.

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