CAIRNS 2023
INTERNATIONAL
SYMPOSIUM
4TH - 7TH SEPTEMBER

Symposium
Paper

cigre

Paper information

Paper number	1219
Paper title	Voltage Regulation and Load Relief in Medium Voltage Feeder Supported by Battery Energy Storage System
Study Committee	SC C6 – Active distribution systems and distributed energy resources
Paper Stream	2. Developing practices, functionalities and applications
Authors	Leonardo LEITE[1], Herbert RAMOS[1], Keverson CARVALHO[2], João Paulo de SOUZA[2], Danilo ALVES[3], Hortênsia AMÉRICO[3], Max LOURENÇO[4], Lígia CARVALHO[4]
Affiliations (optional)	1. Fundação para Inovações Tecnológicas – FITec, 2. Concert Technologies, 3. Cemig Distribuição S.A, 4. Schneider Electric Brasil LTDA
Email address	lleite@fitec.org.br

Summary

The climate change observed in recent years is leading societies, governments, and companies to increase support and investment in a new order of the world's energy matrix, causing the gradual decarbonization of electricity generation. As countries move into a low-carbon economy, there is a significant increase in the use of renewable energy sources, based predominantly on wind, solar and biomass energy.

As solar and wind energy sources are naturally variable, they can introduce problems of stability and power quality to the grid, and new approaches to operation and control in transmission and distribution systems are needed. Specifically, distribution systems have been impacted by the increasing expansion of distributed generation, nodded by the high dispersion of photovoltaic sources installed in the consumer units, imposing several challenges to the operation of the distribution system, such as the increase of system voltage, the inversion of the power flow and the variability of the load/generation ratio due to power flow changes.

Managing the Distributed Energy Resources (DER) present in the distribution system enables greater penetration of Photovoltaic Distributed Generation (PVDG) sources and increases the operational flexibility of the grid. A Distributed Energy Management System (DERMS) tool is therefore critical for the distribution system operator to handle these connected resources in a massive and dispersed manner. The DERMS platform can assist in the operation, maintenance, and planning. DERMS obtains data from dispersed DER connected to distribution network through a capillary communication infrastructure using defined protocols and transforms it into relevant information for the operation center.

This manuscript presents a methodology for DER integration in the Distribution Operation Center so that such resources can be monitored, sensory and controlled, from a DERMS platform, to increase the reliability and quality of the power supply and, at the same time, minimize or mitigate the main impacts caused by these resources. The following will be presented: i) DERMS detailed architecture; ii) Use Cases involving the performance of DERs and iii) Test results related to voltage control and load relief in a 13.8 kV real distribution feeder containing two storage systems (1,150 kVA / 1,750 kWh) and a solar power plant (1.4 MWp).

Keywords

Distributed Energy Resource (DER), Distributed Energy Resource Management System (DERMS), Battery Energy System Storage System (BESS), Load Relief, Voltage Regulation

1. Introduction

The climate change observed in the past years is driving multiple sectors of society to increase investment in renewable energies with the goal of decarbonizing the production of electricity. The main sources of renewable energy are solar and wind generation, which are by nature variable and non-dispatchable. Due to the nature of wind and solar generation, the use of distributed renewable sources can lead to several problems in the distribution systems related to grid stability and energy quality. Therefore, new approaches for operation and control are necessary to overcome the challenges caused by distributed generation to ensure the energy quality and reliability of distribution systems.

The main challenges related to the high penetration of photovoltaic distributed generation are voltage rise and reverse power flow, as shown in [1] and [2]. The insertion of large generation units can also cause problems related to the variability of the load/generation ratio due to changes in power flow direction caused by the intermittence of renewable sources [3].

However, the use of smart inverters in PVDG sources and in Battery Energy Storage Systems (BESS) to mitigate the negative effects of PVDG high penetration has been investigated. A study conducted by [1] that considered hundreds of PVDG penetration scenarios in a real feeder showed that the use of smart inverter control strategies allows greater insertion of PVDG, mitigating the voltage rise problem. A method for BESS optimal dimensioning aiming to accommodate a determined PVDG in a distribution feeder was presented in [4]. A study using data from a real feeder shows how the use of a centralized control structure of BESS to control the reactive power dispatch can increase the efficiency of the feeder and provides support to load transfer, consequently improving grid reliability [5].

In Brazil, the use of PVDG has been becoming popular, reaching 18,2 GW of installed capacity in March 2023 [6]. It is estimated this number will be more than 40 GW by 2030. In addition, several pilot projects involving the use of BESS are being implemented due to the R&D projects conducted by the National Electric Energy Agency (ANEEL) to develop “Technical and Commercial Arrangements for the Insertion of Energy Storage Systems in the Brazilian Electric Sector” [7].

Aggregating the management of DER connected to the distribution system can allow more penetration of PVDG and increase the grid’s operational efficiency. Therefore, having a tool to manage DER is fundamental to enable the distribution operator to deal with mass and disperse connections of DER in the system. This tool is known as DERMS (Distributed Energy Resources Management System) which enables the operator to coordinate the energy dispatch of DER considering technical and economic factors [8], mitigating the voltage rise and ensuring the greater capacity of hosting these resources on the grid [9].

In this context, Companhia Energética de Minas Gerais (CEMIG), the biggest energy distribution company in Brazil, is implementing initiatives to accommodate the increasing demand for PVDG connections by managing the DER on its grid. This work is a result of an investigation conducted on the ANEEL Research and Development projects R&D D649 and R&D D722. The first project presents a methodology for the integration of DER on the distribution grid with the Distribution Operation Center, to enable CEMIG to monitor, measure, and control the DERs using DERMS software to increase reliability and energy quality. The second project analyzes a technical and commercial arrangement for the application of Distributed Energy Storage Systems based on lithium and advanced lead-acid technologies, applied to a critical feeder of the 13.8 kV distribution network.

2. Project Architecture

Figure 1 illustrates the general architecture. The following components are identified:

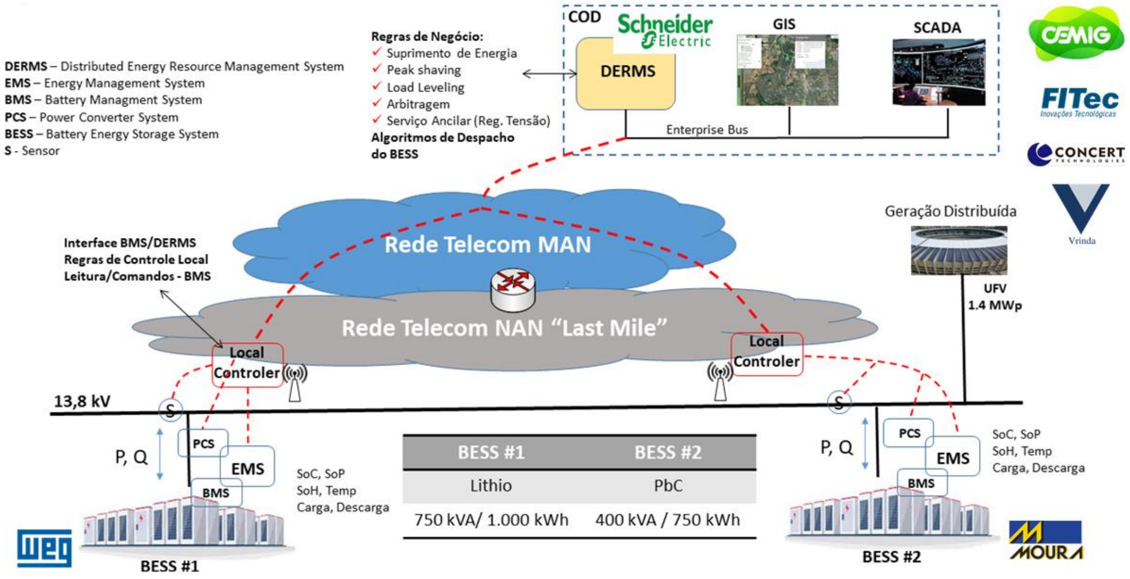


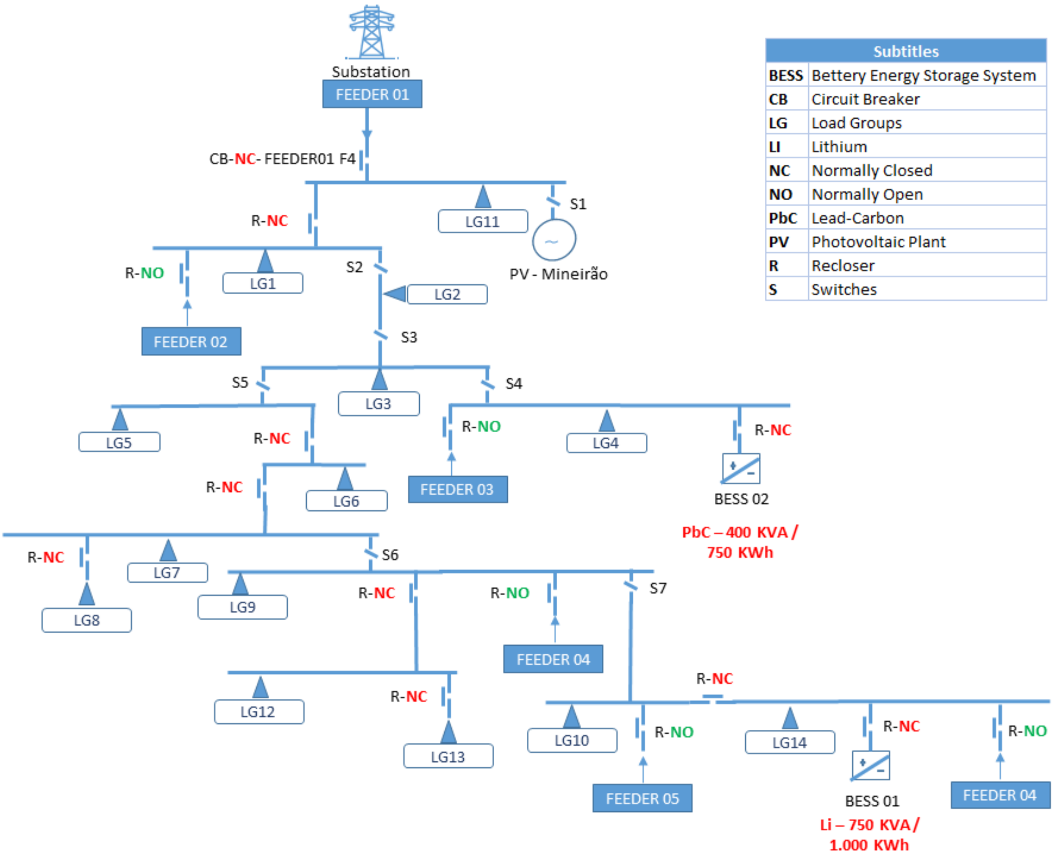
Figure 1 - Project Architecture

- **Battery Energy Storage System (BESS):** this is the whole system of energy storage, including the batteries, the Energy Management System (EMS), the Battery Management System (BMS), the Power Conversion System (PCS) and additional components such as the HVAC system (Heating, Ventilating, and Air Conditioning), the security system and the casing (container).
- **Photovoltaic Power Plant:** 1,42 MWp PV installed on the football stadium roof-top with 5,910 polycrystalline silicon modules of 240Wp each and 88 Smart inverters of 15 kW.
- **Distributed Energy Resource Management System (DERMS):** Tool designed to organize, optimize, manage, and control DER to achieve better financial results, increased reliability and quality of service in the distribution network. The DERMS classifies and manages DER according to their location in the substation, feeder, section of a feeder and generation capacity, among other features. In the context of this project, it will manage the storage systems and implement business rules associated with the functions to be performed as well as the optimal power and energy dispatch of each BESS. In the Distribution Operation Center (COD), the DERMS communicates with other operating systems, such as SCADA and GIS, to receive information related to the power system state. Although DERMS and SCADA are different software platforms, both are usually operated by the same operator within the distribution control room.

2.1 Site Deployment

The feeder selected for the application plant has a total length of 11.9 km and meets a demand of 9.257 MVA distributed to 45 non-residential consumers (33 primary consumers and 12 secondary consumers). It has 7 monopole switches, 1 remote-controlled three-pole switch, 10 remote-controlled reclosers, 59 transformers, and 36 fuse switches. The feeder presents a technical loss of 2.4%. The single-line diagram of the feeder under study is shown in Figure 2.

lleite@fitec.org.br



Subtitles	
BESS	Bettery Energy Storage System
CB	Circuit Breaker
LG	Load Groups
LI	Lithium
NC	Normally Closed
NO	Normally Open
PbC	Lead-Carbon
PV	Photovoltaic Plant
R	Recloser
S	Switches

Figure 2 – Single-line diagram of the feeder. Source: Cemig.

The substation can be seen in the upper part of the diagram, where the feeder originates. This is a strategic feeder, as it has interconnection points not only with feeders of the same substation but also with two other substations. This is an ideal configuration since in case of need, it allows several contingency options. The 14 load groups (LG1 to LG14) and the DER: PV Mineirão, lithium-ion BESS (BESS 01), and lead-carbon BESS (BESS 02) are also presented.

The loads connected to the feeder are grouped into Load Groups (LGs). LGs are divided through network devices, i.e., reclosers or disconnect switches. These devices can be operated locally or remotely to provide power to one or more groups from different sources. The demand for the feeder varies substantially depending on the month, day, and time considered.

Three DER connected to the feeder are considered: PV Mineirão, BESS of Lithium-ion technology (BESS 01), supplied by WEG, and BESS of lead-carbon technology (BESS 02), supplied by Moura. The characteristics of each distributed energy resource are described in Table 1.

Table 1: Characteristics of DER.

Characteristics	Mineirão PV	BESS 01- Li	BESS 02 - PbC
Power	1.400 kVA	750 kVA	400 kVA
Energy	-	1.000 kWh	750 kWh
Technology	Crystalline Silicon Photovoltaic Panel	Lithium (NMC or LFP)	Lead-Carbon (PbC)
Voltage Connection	276 V, 13,8 kV	13,8 kV	13,8 kV
Nominal frequency	60 Hz	60 Hz	60 Hz
Communication Protocol	DNP3	DNP3	DNP3

3. Tests Results

The DERMS platform collects data from distributed energy resources. This information is used to perform real-time network monitoring, resolve system violations, and perform short-term forecasts. The objective of DERMS is to increase the capacity of the existing network to absorb large amounts of DER and meet technical and regulatory restrictions [10].

Among several resources, this work explores the functions of Voltage Regulation and Load Shedding from the control of energy storage systems. For this, two specific functions are of interest:

VVWO - Volt Var Watt Optimization - is the voltage regulation resource used by DERMS. This resource aims at reducing energy consumption, reducing energy losses, improving customer voltage, improving medium voltage, improving power factor, and minimizing the cost of operations. The VVWO can command the DER when a voltage restriction is violated, including over/under voltage and voltage unbalance, so that this violation is resolved. VVWO can be performed manually, semi-automatically, or automatically. When running, a report can be seen with information about the benefits achieved and what command actions were taken [11].

LR – Load Relief - is the load relief resource, which aims to manage current overloads and reverse energy flows. To maintain desired current limits or to avoid reverse flows, this application controls DER to resolve these violations. The output report shows which violations were resolved, the load transferred, how many critical customers were affected, and what switch actions were required [12].

3.1 Voltage Regulation

Intending to improve voltage control on the system buses, distribution networks increasingly rely on connected intelligent, telemetered, and remote-controlled equipment, expanding the visibility of various network parameters when integrated with supervision and control software. Concomitantly, options involving DER can be systematically applied to contribute to the regulation and maintenance of bus voltage at the appropriate levels defined by the regulator.

For the execution of the use case, it was necessary to cause the voltage variation transferring loads from feeder 02 to feeder 01 (see Figure 2). In addition, both BESS initially on stand-by, were configured in the VVWO as resources that could be considered in the solution tracking and optimization process, whose objective function was adjusted to improve the medium voltage buses in a steady state, and no other voltage control feature was used.

The appropriate variation range of the measuring (MV) in relation to the reference voltage (RV) was defined as $0.98\ RV \leq MV \leq 1{,}05\ RV$. Such values were defined for better visualization of the results and the capacity of the VVWO function, not exactly reflecting the Brazilian regulatory determination for medium voltages. Finally, the performance of the VVWO was configured as automatic, that is, when a voltage violation is detected, the function is activated, starting the process of optimization, and searching for solutions. In this case study, DERMS, through the VVWO function, performs the dispatch of 750 kW and 500 kW to BESS 01 and 02, respectively.

The state of charge (SoC) of the batteries is continuously monitored. The VVWO function is only activated after checking a minimum SoC. After dispatch, the BESS are put into charging mode so that the batteries are recharged.

Figure 3 and Figure 4 show feeder 01 voltage profiles before and after the execution of the VWWO. The limits that define the proper voltage range are represented by horizontal lines in red color.

lleite@fitec.org.br

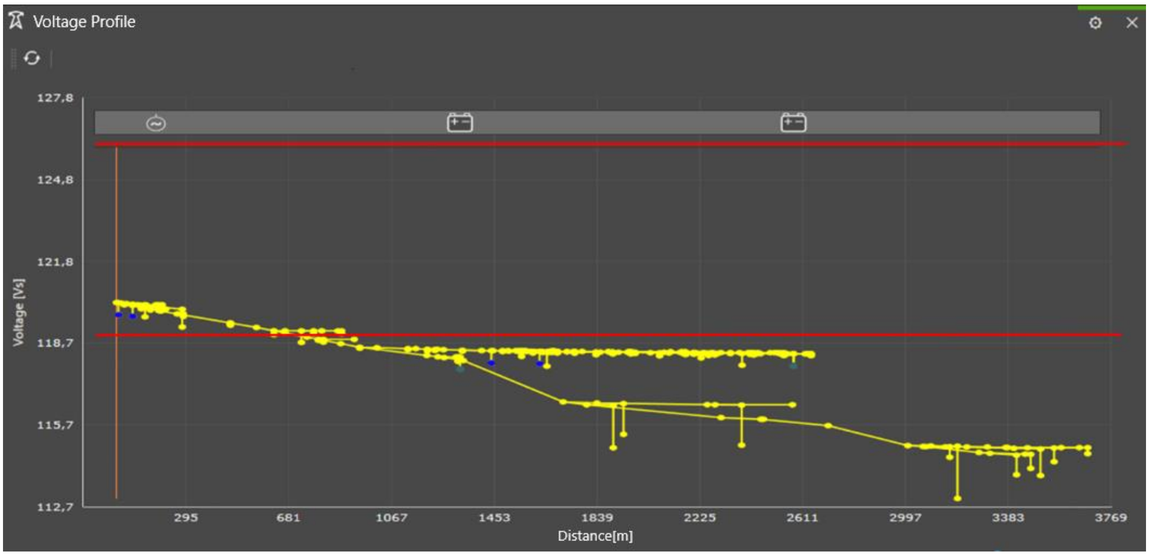


Figure 3- Feeder 01 voltage profile before VVWO execution.

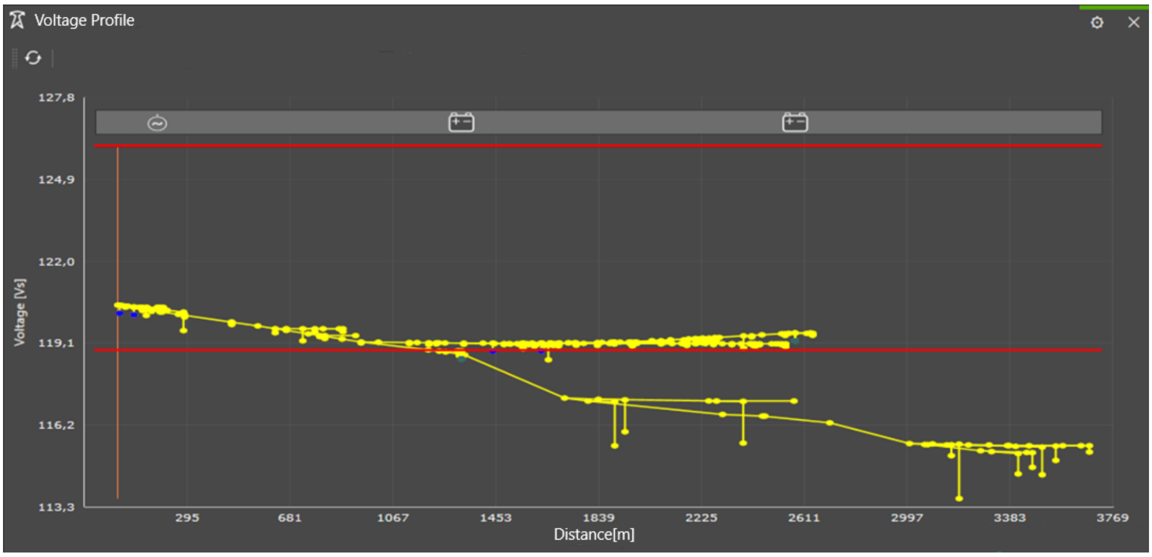


Figure 4- Feeder 01 voltage profile after VVWO execution.

The comparison between the voltage profiles along the length of the feeder shows a considerable impact of the actions performed by the VVWO. According to Figure 3 (before actuation), voltage violations on the feeder start to occur from approximately 0.7 km and intensify downstream of 1.2 km. After VVWO execution, the violations start close to 1.2 km, however, part of the network segments between 0.7 km and 2.6 km was adjusted for operation within the appropriate voltage range. In short, there is an upward shift towards the voltage range defined as adequate, but without changing the general shape of the profile.

3.2 Load Relief

Network parallelism can enable or facilitate the reconfiguration of a distribution network, which typically employs circuit rearrangement in contingency situations, during scheduled shutdowns, and in the event of overloads or reverse flow. In this context, it is possible to isolate faulty sections of the circuit while maintaining the supply in healthy sections and to improve load balancing between feeders, avoiding overload or excess generation in the feeders. In this way, it is possible to improve grid voltage levels and reduce losses in feeders and conductors, in addition to increasing system reliability levels.

The main objective of this function is to allow load transfer without disconnecting consumers for a short period. However, the switching for parallelism must be preceded by studies to verify their technical and operational feasibility.

DERMS supports and assists the operator, offering tools that contribute to assertive decision-making. In the DERMS simulation environment, it is possible to carry out studies from contexts saved in the real-time operation and load them into the simulation environment or even synchronize the simulation environment with the real-time one. This way, the operator can study the switch plan through simulation without affecting real-time operation. If the operation team is interested, they can conduct simulations and evaluations switch plans in future scenarios based on load and generation forecasting tools.

The evaluation of the Load Relief function was considered in a scenario in which feeder 1 has a limit load of 190 A. Under normal conditions, that is, without load transfer from another feeder and with the BESS off, the estimated and measured current is approximately 172 A, as shown in Figure 5.

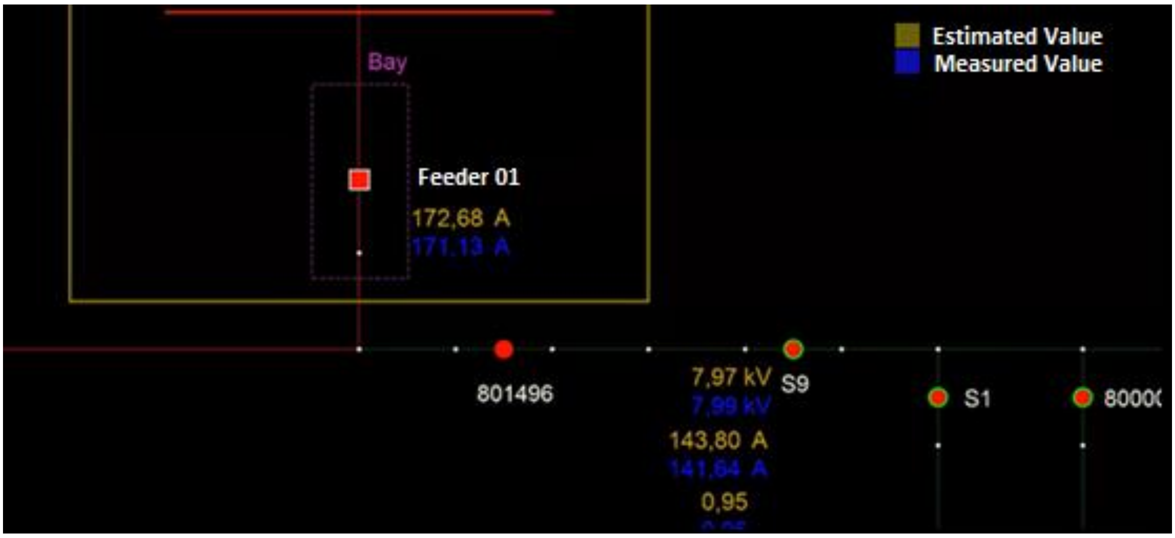
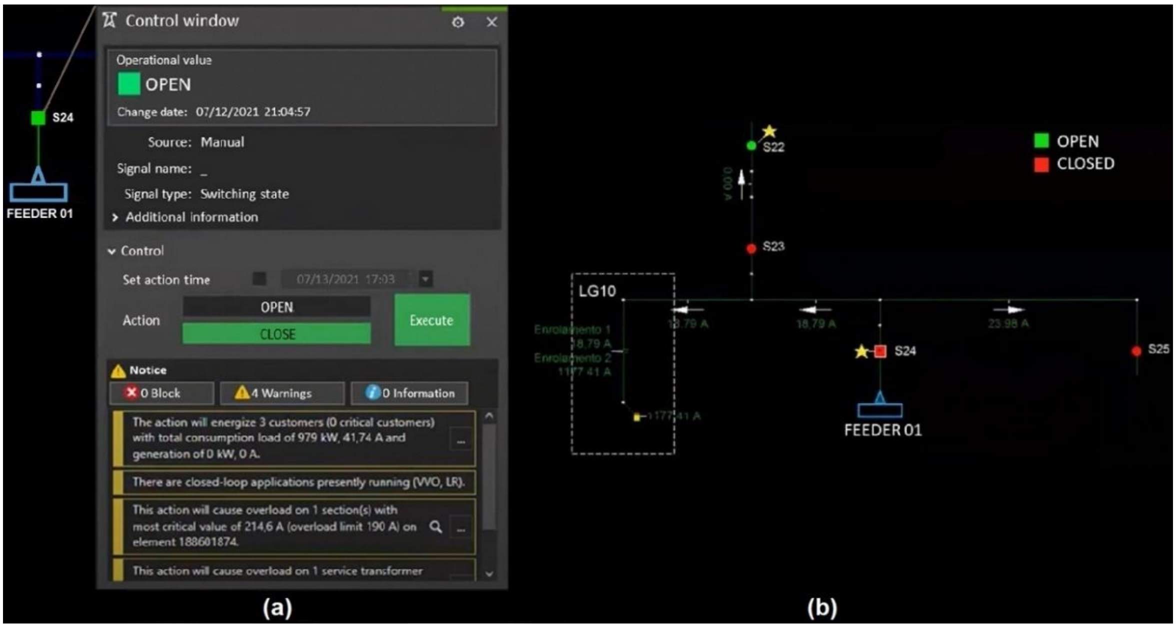


Figure 5 - Estimated and measured current at feeder 01 substation 01.

To evaluate the performance of the load relief function, a load block was transferred from feeder 02 to force an overload on feeder 01. For this purpose, switch S22 and recloser S24 on Feeder 02 were opened and closed, respectively, so that new load groups LG 10, LG11, and LG12 are now supplied by Feeder 01. Before performing the load transfer by changing the state of recloser S24, the command window displays information about this procedure, as shown in Figure 6(a). The warnings indicates that three consumers (979 kW /41,74 A) will be transferred, bringing the operation of feeder 01 to an overload condition. In this case, the current at the feeder output, 172 A before the load transfer, would increase to 214.6 A, extrapolating the allowed overcurrent limit, set to 190 A. Figure 6(b) shows the network after the execution of the load transfer.

lleite@fitec.org.br



Operational value
OPEN
Change date: 07/12/2021 21:04:57
Source: Manual
Signal name: _
Signal type: Switching state

The action will energize 3 customers (0 critical customers) with total consumption load of 979 kW, 41,74 A and generation of 0 kW, 0 A.

There are closed-loop applications presently running (VVO, LR).

This action will cause overload on 1 section(s) with most critical value of 214,6 A (overload limit 190 A) on element 188601874.

This action will cause overload on 1 service transformer

Figure 6- Load transfer between feeders: (a) S24 recloser control window warnings and (b) the grid after the transference.

This overload condition activates the DERMS load relief function to solve the problem. BESS 01 and BESS 02 were dispatched to deliver 750 kW and 400 kW, respectively. As a result, the abnormal overload operation on Feeder 01 was brought to normality, where the current at the feeder output stabilized at 174.1 A, lower than the configured overcurrent limit. Table 2 summarizes the test results.

Table 2 - Operational support for load transfer – Load Relief Function.

Scenario - feeder limit: 190 A	Initial condition	After load transfer	Control action (LR)
Feeder output current (A)	172	214,6	174,1
BESS 01 dispatch (kW)	-	-	750
BESS 02 dispatch (kW)	-	-	400

4. Operational Challenges

In this new paradigm of operation of distribution systems due to the high penetration of DER and the increased complexity caused by the bidirectional flow of information and load, the role of distribution operators is changing from centralized actions to a more decentralized approach, to accommodate new alternatives in the respective processes of operation and planning.

Currently, most of the DER in Brazil are owned by third parties and the distribution companies do not have visibility or control over them, which imposes difficulties in the planning of the operation and expansion of distribution systems. Furthermore, the insertion of distributed energy resources without a proper management may incur associated problems, such as voltage violations, unbalance between load and generation, overload, and reverse flow, among others. Therefore, it is essential to know the behavior of these assets connected to the electric grid and supervise and control them, so that such difficulties are mitigated or minimized.

The main operational challenges observed as a result of this R&D project are: (i) the integration of DERMS platform with the other supervision and control systems as pre-existing SCADA and GIS is not

lleite@fitec.org.br

a simple task, requiring standardization of the communication interfaces and specific procedures related to the synchronization of the database common to these systems, (ii) a capillary communication infrastructure, which allows connectivity between the control center with multiple distributed energy resources dispersed over an extensive geographical area considering technical and quality of service requirements is a challenge for distribution companies, and (iii) although there is a potential market for distributed energy resources to provide ancillary services to the grid, the control of DER from third parties by the distribution companies is not yet allowed by Brazilian legislation, which hinders operational agreements between energy providers and prosumers.

The costs of deployment and operation of a DERMS platform by distribution companies is justified in a scenario of high dispersion of distributed energy resources, especially when connected to more critical feeders. Economic analysis should consider the contribution of DERMS to reduce fines for voltage and continuity of supply violations, to reduce technical losses and to postpone investments in the distribution power grid.

5. Conclusions

The insertion of DER in CEMIG's distribution network has shown accelerated growth in the last 5 years. This scenario is also a reality in most Brazilian energy distributors. However, some feeders in CEMIG's distribution network are already being affected by the high dispersion of DER: high reverse flow, violation of voltage limits, protection system failure, etc., resulting in fines and financial compensation paid by the distributor to consumers.

The accelerated growth of variable and dispersed energy sources in the network demands smarter and more flexible distribution network planning and operation actions, which justifies the need for new operational procedures and computational resources for distributed energy resource management.

The results achieved in this R&D project showed the positive impacts on the actions of supervision and control of DER by the Distribution Operation Center using integrated DERMS platform.

However, it is necessary to expand the analyses considering a geoelectric set of greater amplitude in terms of the number of feeders with high DER dispersion and feeders with low quality and energy supply indexes.

Acknowledgment

The authors thank the Research and Development Program of the Brazilian electricity sector regulated by ANEEL and CEMIG - Companhia Energética de Minas Gerais, for their financial and technical support to this R&D project.

Bibliography

[1] TEIXEIRA, Lucas de Godoi, LEITE, Leonardo Henrique de Melo, JUNIOR, Johnny Mafra, BOAVENTURA, Wallace do Couto and ALESSI, Pedro Machado, "The Effect of Local Inverter Voltage Control in Technical Losses on Low Voltage of a Brazilian Distribution Feeder with Increasing PV Penetration," 2019 IEEE PES Innovative Smart Grid Technologies Conference - Latin America (ISGT Latin America), 2019, pp. 1-6, doi: 10.1109/ISGT-LA.2019.8894950.

[2] AZIZ, T and KETJOY, N., "PV Penetration Limits in Low Voltage Networks and Voltage Variations," in IEEE Access, vol. 5, pp. 16784-16792, 2017, doi: 10.1109/ACCESS.2017.2747086.

[3] PLATT, G., WES, T. and MOORE, T., "The real-world challenges and opportunities of distributed generation," 2015 IEEE Energy Conversion Congress and Exposition (ECCE), 2015, pp. 1112-1116, doi: 10.1109/ECCE.2015.7309814.

[4] BASS, R. B., CARR, J., AGUILAR, J. and Whitener, K., "Determining the Power and Energy Capacities of a Battery Energy Storage System to Accommodate High Photovoltaic Penetration on a Distribution Feeder," in IEEE Power and Energy Technology Systems Journal, vol. 3, no. 3, pp. 119-127, Sept. 2016, doi: 10.1109/JPETS.2016.2586072.

[5] Souza, J.P.A., Leite, L.H.d., Teixeira, L.d. et al. Analysis of Reactive Power Control Using Battery Energy Storage Systems for a Real Distribution Feeder. J Control Autom Electr Syst (2022). https://doi.org/10.1007/s40313-021-00877-9

[6] ANEEL BIG - Banco de Informação de Geração ANEEL - Gerção Distribuída. Acesso em 26/01/22. Disponível em: http://www2.aneel.gov.br/scg/gd/GD_Fonte.asp

[7] ANEEL - CHAMADA NO 021/2016 PROJETO ESTRATÉGICO: “ARRANJOS TÉCNICOS E COMERCIAIS PARA A INSERÇÃO DE SISTEMAS DE ARMAZENAMENTO DE ENERGIA NO SETOR ELÉTRICO BRASILEIRO”. Agência Nacional de Energia Elétrica – ANEEL Superintendência de Pesquisa e Desenvolvimento e Eficiência Energética – SPE. Brasília, DF Julho de 2016.

[8] Wang, Jianhui, Chen, Chen, and Lu, Xiaonan. Guidelines for Implementing Advanced Distribution Management Systems-Requirements for DMS Integration with DERMS and Microgrids. United States: N. p., 2015. Web. doi:10.2172/1212266.

[9] Renjit, Ajit et al. Evaluating the Value of DERMS: Methods and Mitigation to Increase Feeder Hosting Capacity. 2019.

[10] SCHNEIDER DERM, Schneider Electric, "EcoStruxure DERMS Distributed Energy Resource Management System: Functional Specification" Version 1.0, July 2020.

[11] SCHNEIDER VVWO, Schneider Electric, "EcoStruxure DERMS Volt Var Watt Optimization: Functional Specification" Version 2.0, Nov. 2020.

[12] SCHNEIDER LR, "EcoStruxure DERMS Load Relief: Functional Specification" Version 2.0, Nov. 2019.

lleite@fitec.org.br