Microgrid Dispatch with Protection Constraints

Mateo Beus
University of Zagreb
Faculty of Electrical
Engineering and Computing
Zagreb, Croatia
Email: mateo.beus@fer.hr

Ivan Grcić
University of Zagreb
Faculty of Electrical
Engineering and Computing
Zagreb, Croatia
Email: ivan.grcic@fer.hr

Hrvoje Pandžić
University of Zagreb
Faculty of Electrical
Engineering and Computing
Zagreb, Croatia
Email: hrvoje.pandzic@fer.hr

2021 International Conference on Smart Energy Systems and Technologies (SEST) | 978-1-7281-7660-4/21/$31.00 ©2021 IEEE | DOI: 10.1109/SEST50973.2021.9543224

***Abstract*—This paper introduces a two-level microgrid dispatch procedure that takes into account microgrid protection settings. The first dispatch level is based on a dynamic economic dispatch algorithm that considers frequency-aware islanding constraints, ensuring the frequency stability of the microgrid during unplanned islanding transitions. The results of the first dispatch level are used as inputs to the load flow calculations performed in the second dispatch level. Based on the load flow calculations, the overcurrent, i.e. overload, and voltage protection settings in the microgrid during the first 15 minutes after a re-dispatch may be set to less conservative values if needed. In this way, the microgrid's operating region is expanded ensuring that tripping of the current or voltage protection relays will not cause a microgrid outage during the first 15 minutes after the dynamic economic dispatch was performed. After this 15-minute period, the voltage and current protection settings will be set to default, i.e. grid-connected or islanded, operating mode values. The case studies presented demonstrate the effectiveness of the proposed microgrid dispatch scheme. Two-level dispatch was compared with the standard economic dispatch and showed increased reliability of power supply.**

***Index Terms*—control architecture, economic dispatch, microgrid protection, overcurrent protection.**

I. Introduction

Secure and reliable operation of microgrids can be jeopardized during a transition between the grid-connected and the islanded operating modes due to frequency disturbances or cables/lines overloading. Namely, an unplanned power imbalance due to an islanding event can trigger frequency protection relays within the microgrid to shed some production units or loads in order to prevent under-or-over frequency collapse. Furthermore, the change in the operating mode of a microgrid can lead to power flow changes within the microgrid causing cables/lines overloading or even fluctuations of the voltage profile. This can trigger over-current protection relays, i.e. overload protection, or even voltage protection relays to disconnect some cables/lines leading to a microgrid outage. Therefore, it is necessary to develop energy management system (EMS) tools capable of taking into account the microgrid's protection settings.

The layout of the paper is as follows. In the Section II, an overview of the publications related to the protection strategies and optimization of microgrid operation is given along with the contribution. Two-level microgrid dispatch procedure is introduced in Section III. The microgrid setup used to validate the proposed dispatch scheme and the simulation results are presented in Section IV. The paper is concluded in Section V.

II. Literature review and Contribution

In the context of the short-term optimization of microgrid operation (up to one day), which is related to the first dispatch level proposed in this paper, a considerable amount of literature exists. Economic dispatch algorithms available in the literature usually do not take into account microgrid protection settings. However in [1]– [2], the authors integrated security constraints within an economic dispatch framework. Paper [1] introduced a security-constrained multi-objective optimal dispatch framework for an economic and reliable operation of microgrids, while [2] integrated frequency-aware constraints within the economic dispatch procedure. The current practice in the microgrid dispatch procedure is to apply a relatively simple capacity-based reserve requirement in the microgrid real-time dispatch problem [3]– [5]. In this way, the total primary reserve requirement is set to the capacity of the largest production unit within the microgrid or a fixed percentage of its peak load. This strategy leads to inefficient operation of the microgrid. Moreover, the frequency stability during unplanned islanding transitions can not be guaranteed.

In [6]– [7], the authors developed a Mixed-Integer Nonlinear Optimization Problem (MINLP) for optimal operation of a microgrid. In both papers, MINLP optimization problems performed the role of an EMS. The main purpose of an EMS formulated in this way was to perform optimal operation and scheduling of microgrids. However, the main disadvantage of the proposed algorithms lies in ignoring the security/protection constraints within the microgrid.

Generally, the concept of microgrids was introduced as an attractive solution to exploit the benefits offered by distributed energy resources (DER). However, despite their numerous advantages, microgrids can have a negative impact on conventional protection practices in the distribution networks. The negative impact of DERs on a microgrid's protection scheme can be seen in the following ways [8]:

- Fault detection failure in the islanding operation mode,
- Misoperation of reverse-power and/or non-directional protection functions,
- Exceeding equipment rating due to higher current rating,

- Sympathetic tripping on adjacent feeders due to DER fault current contributions,
- Protection miscoordination issues.

In that regard, it is important to analyze the existing protection schemes that have been implemented in the current microgrid projects. In [9], the authors provide a comprehensive review of the protection schemes in real-world microgrid projects, while in [10], an overview of fault detection methods for islanded inverter-based microgrids was provided. Fig. 1 shows an overview of the protection schemes in the microgrids derived from the literature.

Furthermore, in [11]– [12], an overview of fault detection methods in DC microgrids is provided. Nowadays, DC protection strategies also gained in importance since microgrids usually have hybrid topology, i.e. a microgrid can consist of the AC and the DC parts coupled by bi-directional converters.

The contribution of this paper lies in increasing the reliability and operational flexibility of the microgrid. In that regard, this paper introduces a two-level microgrid dispatch procedure that takes into account the microgrid's protection settings. The first dispatch level is based on a dynamic economic dispatch (DED) algorithm that considers frequency-aware islanding constraints to maintain the frequency stability of the microgrid during unplanned islanding transitions, proposed in [2]. The second level uses optimal active power set points, provided by the first dispatch level, for every dispatchable element in the microgrid as inputs for load flow (LF) calculations in the microgrid. Additionally, voltage measurements from each bus of the microgrid are also provided as inputs for LF calculations. Based on the load flow calculations, the overcurrent and over/undervoltage protection settings in the microgrid during the first 15-minutes after a re-dispatch may be set to less conservative values if needed. This interval is chosen equal to the period between two consecutive DED calls and can be further modified. Moreover, the overload of power line is allowed for certain time interval [17].

III. Microgrid Dispatch Framework

The microgrid dispatch procedure designed in this paper consists of two levels elaborated in **Algorithm 1**. The first dispatch level is based on an DED algorithm that takes into account frequency-aware islanding constraints to maintain the frequency stability of the microgrid during unplanned islanding transitions. The results of this dispatch level, i.e. optimal active power set points for dispatchable units, are used as inputs to the second dispatch level that performs load flow calculations. Furthermore, voltage measurements from each bus in the microgrid serve as inputs for the load flow calculations as well. Based on these calculations, the overcurrent and over/undervoltage protection settings in the microgrid during the first 15 minutes after a re-dispatch may be set to less conservative values. In this way it is possible to expand the microgrid operating region ensuring that tripping of the current or voltage protection relays does not cause the outage of the microgrid during the first 15 minutes after a re-dispatch.

OFFLINE:
1. Define DED algorithm parameters
2. Define default protection settings for grid-connected and islanded mode of operation

ONLINE:

while *Dispatch procedure is enabled* **do**
    if *15 minutes passed since the last call* **then**
        1. Read initial active power measurements to determine microgrid's operating point p_g^{INIT}, P_{RES}, C_l, NL
        2. Read initial frequency f and $rocof$ measurements
        3.**CALL** DED algorithm
        4. Send DED algorithm results (optimal active set points) for each dispatchable unit to the LF algorithm
        5.Read and send voltage measurements from each bus in the MG
        to the LF algorithm
        6.**CALL** LF algorithm
        7.**if** *current exceeds limitations and the flag is 0* **then**
            7.1.Increase default settings for over-current protection by 20%
            7.2 Set the the flag to 1
        end
        8.**if** *voltage exceeds limitations and the flag is 0* **then**
            8.1.Increase default settings for over/under voltage protection by 20%
            8.2 Set the flag to 1
        end
        9.**if** *15 minutes passed since the flag was set to 1* **then**
            9.1. Set the flag to 0
            9.2 Set the protection setting to default values
        end
    end
end

Algorithm 1: Dispatch procedure

A. DED – the first dispatch level

In this subsection, we introduce the DED formulation used in the first dispatch level. Table I shows variables and parameters used in the formulation of the optimization problem. The main goal of the first dispatch level is to perform minimization of the operating costs while ensuring islanding capability at any moment. The DED optimization problem is formulated as follows:

1) Objective function:

$$\min \sum_{t=1}^{T} (\sum_{g=1}^{N_g} k_{1,g} p_{g,t} + k_2 u_t) + \sum_{t=1}^{T} \sum_{g=1}^{N_g} (k_{3,g} r u_{g,t} + k_{4,g} r d_{g,t}) \tag{1}$$

2) Operation constraints:

$$\sum_{g=1}^{N_g} p_{g,t} + P_{RES} + u_t \geq \sum_{l=1}^{N_l} C_{l,t} + NL_t \tag{2}$$

$$\sum_{t=1}^{T} \sum_{l=1}^{N_l} C_{l,t} = \sum_{t=1}^{T} \sum_{l=1}^{N_l} L_{l,t} \tag{3}$$

$$U^{\mathrm{MIN}} \leq u_t \leq U^{\mathrm{MAX}} \tag{4}$$

$$P_g^{\mathrm{MIN}} \leq p_{g,t} \leq P_g^{\mathrm{MAX}} \tag{5}$$

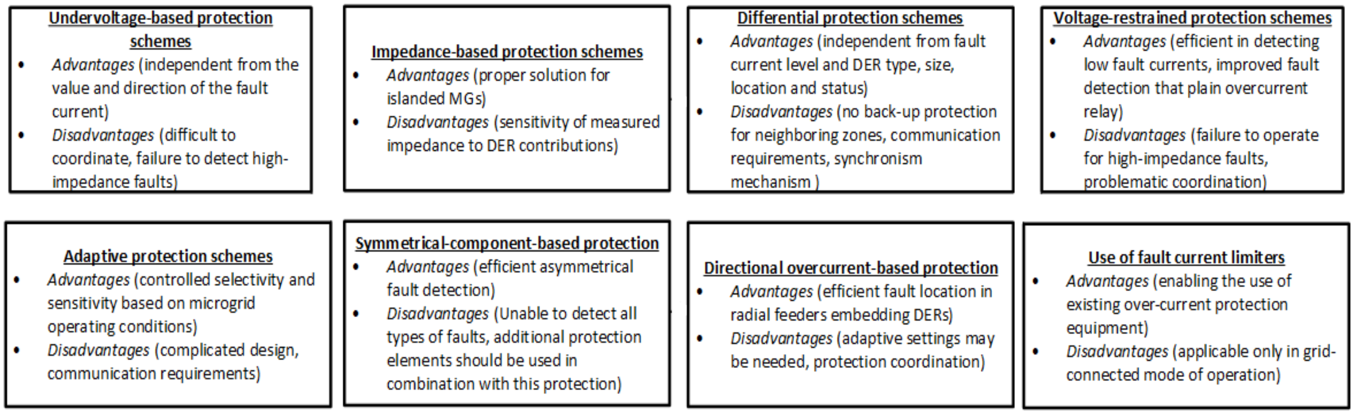

Fig. 1: Microgrid Protection Schemes – an overview [9], [13], [14].

$$p_{g,t+1} - p_{g,t} \leq RU_g^{\mathrm{MAX}} \tag{6}$$

$$p_{g,t_1} - p_g^{\mathrm{INIT}} \leq RU_g^{\mathrm{MAX}} \tag{7}$$

$$p_{g,t-1} - p_{g,t} \leq RD_g^{\mathrm{MAX}} \tag{8}$$

$$p_g^{\mathrm{INIT}} - p_{g,t_1} \leq RD_g^{\mathrm{MAX}} \tag{9}$$

$$p_g^{\mathrm{MIN}} \leq p_{g,t} + ru_{g,t} \leq p_g^{\mathrm{MAX}} \tag{10}$$

$$p_g^{\mathrm{MIN}} \leq p_{g,t} - rd_{g,t} \leq p_g^{\mathrm{MAX}} \tag{11}$$

$$PUP_g^{\mathrm{MIN}} \leq ru_{g,t} \leq PUP_g^{\mathrm{MAX}} \tag{12}$$

$$PD_g^{\mathrm{MIN}} \leq rd_{g,t} \leq PD_g^{\mathrm{MAX}} \tag{13}$$

$$rocof_t = (\sum_{g=1}^{N_g} p_{g,t} - Df_{t-1} - u_t)/2H \tag{14}$$

$$rocof^{\mathrm{MIN}} \leq rocof_t \leq rocof^{\mathrm{MAX}} \tag{15}$$

$$f_t = f_{t-1} + rocof_t \tau \tag{16}$$

$$f^{\mathrm{MIN}} \leq f_t \leq f^{\mathrm{MAX}} \tag{17}$$

The first term in objective function (1) represents energy production costs of dispatchable units, the second term represents the cost/profit from the interaction with the utility grid, while the third term represents the cost associated with the provision of primary reserve. Constraint (2) is the power balance equation. Constraint (3) ensures that the total energy of the dispatchable loads does not change over the operating horizon, since dispatchable loads have the possibility to provide demand response. Equations (4)–(9) represents technical constraints that each dispatchable unit needs to satisfy. Namely, constraint (4) defines the upper and lower limits of the power exchanged with the utility grid, while constraint (5) limits the power output of each dispatchable unit. Ramp-up and ramp-down constraints of dispatchable units are defined in (6)–(7) and (8)–(9), respectively. Furthermore, the upward and downward reserves of dispatchable units are defined in (10)–(11) and (12)–(13), respectively. Constraints (14)–(17) are frequency-aware constraints as defined in [2]. Constraint (14) is derived from the frequency dynamics of the microgrid during an islanding event and is used to determine the rate of change of frequency (ROCOF), whose value is implied by constraint (15). In (16), the instantaneous frequency is calculated from the previous time step frequency and ROCOF. The constraint (17) limits the frequency. These constraints make sure that the dispatch procedure can guarantee the stability of the microgrid after a sudden transition from the grid-connected into the islanding mode of operation.

B. LF – the second dispatch level

The DED provides the power output of each generator, but to determine the bus voltages, the load flow problem must be solved. Once each bus voltage is known, it can be determined if the protection settings are violated. One of the most common methods for solving the LF problem is the Newton-Raphson method, where the root of the function is found by iterative approximation using Taylor expansion. The prerequisite is that the function is continuous and differentiable. Higher order Taylor expansion terms are neglected, i.e., the function is approximated with the tangent at a selected point and the root of the tangent is found and used as input in the next iteration. Once the deviation of the function from zero is within acceptable limits, the process is stopped [15]. The NR method applied in this framework used 0.1 MVA as base power, accuracy was set to 0.0001 and the maximum number of iterations was limited to 10000.

Based on the LF calculations performed in the second dispatch level, the overcurrent and over/undervoltage protection settings in the microgrid may be set to less conservative values if needed for a limited period of time. In reality, higher excursion from the nominal values is allowed since lines and cables can be overloaded for a limited amount of time. After the 15-minute period, the voltage and current protection settings will be set to the default values. In this way it is possible to expand the microgrid's operating region, ensuring that tripping of the current or voltage protection relays does not cause a microgrid outage during the first 15 minutes after the re-dispatch procedure performed in the first, i.e. DED, dispatch

TABLE I: Parameters and variables in the first dispatch level.

Parameters	Description
N_g	Number of DG units
N_l	Number of dispatchable loads
NL	Total consumption level of non-dispatchable loads [kW]
$P_g^{\mathbf{MIN}}$	Minimum power level of a DG unit [kW]
$P_g^{\mathbf{MAX}}$	Maximum power level of a DG unit [kW]
$U^{\mathbf{MIN}}$	Min. power level limit exchanged with utility grid [kW]
$U^{\mathbf{MAX}}$	Max. power level limit exchanged with utility grid [kW]
$f^{\mathbf{MAX}}$	Maximum allowed frequency limit [Hz]
$f^{\mathbf{MIN}}$	Minimum allowed frequency limit [Hz]
$rocof^{\mathbf{MAX}}$	Maximum allowed rocof limit [Hz/s]
$rocof^{\mathbf{MIN}}$	Minimum allowed rocof limit [Hz/s]
H	Microgrid inertia level
D	Load damping factor
τ	Microgrid discretization step-size [s]
$PUP_g^{\mathbf{MAX}}$	Maximum limit of upward reserve [kW]
$PUP_g^{\mathbf{MIN}}$	Minimum limit of upward reserve [kW]
$PD_g^{\mathbf{MAX}}$	Maximum limit of downward reserve [kW]
$PD_g^{\mathbf{MIN}}$	Minimum limit of downward reserve [kW]
$RU_g^{\mathbf{MAX}}$	Ramp up limit of a DG unit [kW/h]
$RD_g^{\mathbf{MAX}}$	Ramp down limit of a DG unit [kW/h]
P_{RES}	Total power production from RES [kW]
L_l	Forcasted power level of a dispatchable load [kW]
$p_g^{\mathbf{INIT}}$	Active power measurements of DG units [kW]
k_1	Production cost [EUR/kWh]
k_2	Energy price [EUR/kWh]
k_3	Upward reserve price [EUR/kWh]
k_4	Downward reserve price [EUR/kWh]
Variables	**Description**
f	Microgrid frequency [Hz]
$rocof$	Rate of change of frequency [Hz/s]
C_l	Dispatchable load consumption level [kW]
p_g	Power level of a DG unit [kW]
u	Power exchanged with the utility grid [kW]
ru_g	Upward primary reserve [kW]
rd_g	Downward primary reserve [kW]

level. The over-current protection is realized based on IEC 60255 trip curves. Positions of protection relays, i.e. OC1-OC15 in the microgrid are illustrated in Fig. 2. Tripping time for each relay is calculated based on the following equation:

$$T(I) = TMS\left(\frac{k}{(\frac{I}{I_s})^{\alpha}} - 1\right) \tag{18}$$

where I_s is the current setting, I is actual current, and k and α are the curve type constants. In this case standard inverse curve was used indicating that k value is 0.14 and α is 0.02. TMS represents time-multiplier whose default value is 0.5.

IV. Results and Discussion

A. Simulation setup

The introduced dispatch framework is validated on a CIGRE benchmark 0.4 kV residential subnetwork that represents a microgrid, connected to the 21 kV, 50 Hz utility grid [16]. The microgrid's single-line diagram is illustrated in Fig. 2. Line and non-dispatchable load parameters are given in Tables II and III. Furthermore, two dispatchable DER production units, i.e. a small-scale hydro power plant and a diesel unit, and one non-dispatchable RES unit, i.e. wind power plant, are integrated in the microgrid. Additionally, two dispatchable loads are integrated in the microgrid to provide demand response. The parameters for dispatchable production/consumption units are given in Table IV. DED and LF are calculated using Matlab R2020a, and the microgrid model is simulated in Matlab Simulink software.

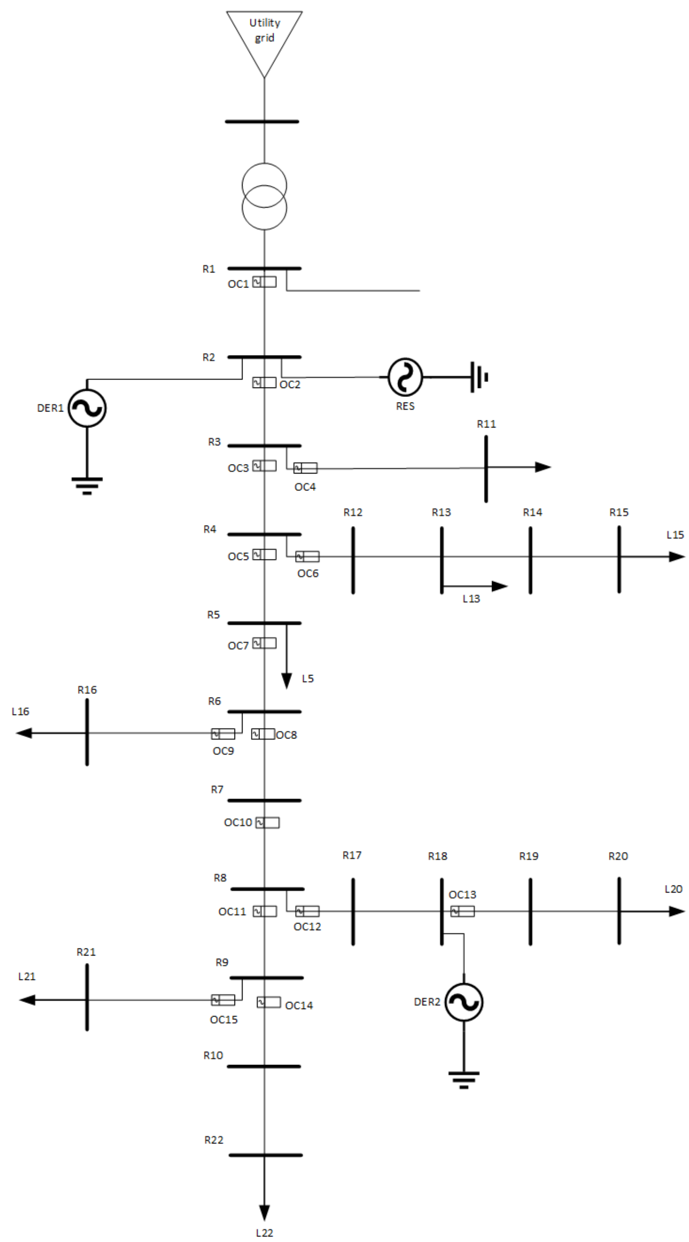

Fig. 2: Microgrid topology [16].

TABLE II: Line Parameters [16].

Line	R1(Ω/km)	X1(Ω/km)	l(km)
R1-2, R2-3, R3-4, R4-5, R5-6, R6-7, R7-8, R8-9, R9-10	0.162	0.0832	0.035
R3-11, R6-16, R9-21, R10-22, R14-15, R19-20	0.822	0.0847	0.03
R4-12, R8-17, R12-13, R13-14, R17-18, R18-19	0.822	0.0847	0.035

TABLE III: Load Parameters.

Loads	P(kW)	Q(kvar)
L11	14.2	4.6
L15	49.4	16.2
L16	52.2	17.1
L20	49.4	16.2
L21	33.2	10.9
L22	44.6	14.6

TABLE IV: Production units parameters.

Unit	P_{min} (kW)	P_{max} (kW)	Ramp-up/down (kW/min)
DER1	5	200	75/75
DER2	10	150	100/100
RES	0	100	100/100
L5	0	25	25/25
L13	0	25	25/25

B. Results

In this section we present two simulation cases demonstrating the functionality of the proposed dispatch framework. In both simulation cases the microgrid operates in the grid-connected mode. Furthermore, it should be emphasized that dispatchable loads in both simulation cases have the ability to provide DR as specified in constraint (3), i.e. the total energy consumption is constant over the prediction horizon. The main difference between the presented simulation cases is in the usage of the LF dispatch level. Namely, in the first case the LF level is disabled. This indicates that the DED algorithm in the first dispatch level does not consider over-current and over voltage protection settings. In the second case, the LF level is enabled, thus enabling the protection settings in the microgrid. Both simulation cases are conducted with a 15-minute prediction horizon and a time step of 1 minute. Since the microgrid operates in the grid-connected mode, the main objective of the first dispatch level in both simulation cases is to minimize the microgrid operating costs, while at the same time taking in account the frequency-aware islanding constraints to maintain the frequency stability of the microgrid during unplanned islanding transitions. During both simulation cases, the wind power plant production level is 74.28 kW. Furthermore, in both simulation cases the dispatch procedure is disabled during the first 2 minutes. During this period, DER1 unit, i.e hydro power plant, operates initially at 18.5 kW, DER2 unit, i.e. diesel unit, operates at 45.2 kW, while power of both dispatchable loads is 0 kW. The total power of non-dispatchable loads during both simulation cases is 206.3 kW. Simulation results for both simulation cases are shown in Figs. 3 and 5. In the first simulation case, the second dispatch level, i.e. LF level, is disabled leading to the microgrid outage. Namely, the dispatch procedure executed at t=2 min caused the current levels through certain cable sections in the microgrid exceed the over-current protection settings, thus causing tripping of over-current relays. This is visible for the cable section between R2 and R3 whose pick-up current I_s for the OC2 over-current protection relay was set to 250 A. However, the DED procedure performed at t=2 min caused an increase of the current through this section to 290 A. Fig. 4 shows the current measurements through the cable section between R2 and R3 in the first simulation case. In the second simulation case, the second dispatch level is enabled, which prevents the microgrid outage. Namely, the dispatch procedure executed at t=2 min caused the current levels through some sections in the microgrid exceed the default over-current protection settings for the grid-connected mode of operation. However, the LF level calculations indicated that the current level through some cable sections of the microgrids will be higher than the default pick-up current I_s in the over-current protection settings. In reality, cables and lines are allowed to be overloaded for a limited amount of time. Therefore, the LF level increased the value of the pick-up current I_s for the over-current protection by 20% during a 15-minutes time period. For this simulation case, Fig. 6 shows that the current measurements through the cable section between R2 and R3 are higher than nominal 250 A. However, during this 15-minute time period, the LF level increased the pick-up current level for this section from 250 A to 300 A, preventing the over-current relay OC2 to trip as in the previous simulation case. This operation ensures additional flexibility in the microgrid during critical situations. Furthermore, the security of the microgrid during fault conditions, i.e. short circuit, is not jeopardized since the pick-up current levels for the instantaneous over-current trip curve were not changed.

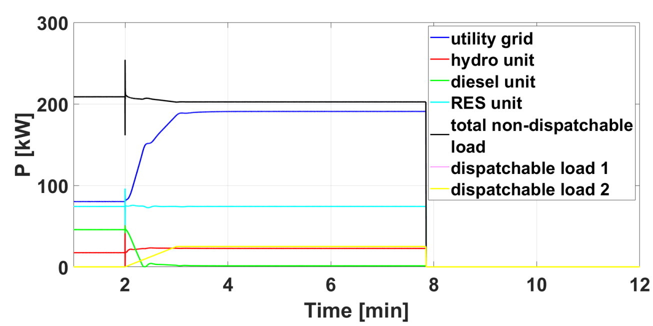

Fig. 3: Simulation case 1.

V. Conclusion

The main objective of this paper was to present a two-level microgrid dispatch procedure that takes into account the microgrid protection settings. The first dispatch level is based on a DED algorithm that considers frequency-aware

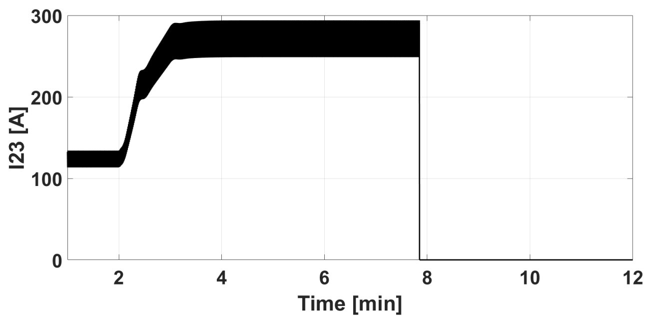

Fig. 4: Simulation case 1 – current measurements through section between R2 and R3.

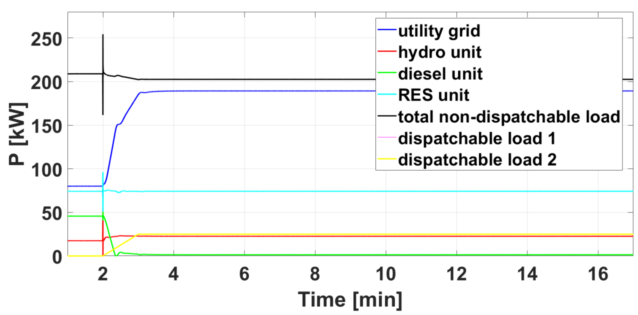

Fig. 5: Simulation case 2.

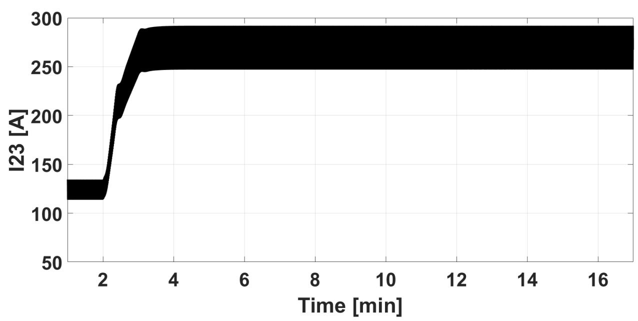

Fig. 6: Simulation case 2 – current measurements through section between R2 and R3.

islanding constraints, ensuring the frequency stability of the microgrid during unplanned islanding transitions. The second dispatch level is based on the Newton-Raphson load flow calculation. Based on the load flow calculations, overcurrent, i.e. overload, and voltage protection settings in the microgrid can be set to less conservative values during 15-minutes time period after the re-dispatch expanding the operating region of the microgrid. The functionality of this dispatch framework has been validated on the CIGRE benchmark low voltage microgrid. The effectiveness of this framework is demonstrated by performing the simulations in grid-connected mode. The main focus of further research will be on validation of the proposed framework during the transitions between the grid-connected and the islanded mode of operation.

Acknowledgment

This work was supported by the Croatian Science Foundation and European Union through the European Social Fund under the project Flexibility of Converter-based Microgrids–FLEXIBASE (PZS-2019-02-7747), as well as the Croatian Science Foundation and Croatian Distribution System Operator (HEP ODS) under the project Innovative Modelling and Laboratory Tested Solutions for Next Generation of Distribution Networks–IMAGINE (PAR-2018-12).

References

[1] V. Sarfi and H. Livani, "An Economic-Reliability Security-Constrained Optimal Dispatch for Microgrids," *IEEE Transactions on Power Systems*, vol. 33, no. 6, pp. 6777-6786, May 2018.

[2] Y. Wen, C. Y. Chung, X. Liu and L. Che, "Microgrid Dispatch with Frequency-Aware Islanding Constraints," *IEEE Transactions on Power System*, vol. 34, no. 3, pp. 2465-2468, 2019.

[3] Q. Jiang, M. Xue and G. Geng, "Energy management of microgrid in grid-connected and stand-alone modes," *IEEE Trans. Power Syst.*, vol. 28, no. 3, pp. 3380-3389, 2013.

[4] S. Khan, W. Gawlik and P. Palensky, "Reserve capability assessment considering correlated uncertainty in microgrid," *IEEE Trans. Sustain. Energy*, vol. 7, no. 2, pp. 637-646, 2016.

[5] C. Hernandez-Aramburo, T. C. Green and N. Mugniot, "Fuel consumption minimization of a microgrid," *IEEE Trans. Ind. Appl*, vol. 41, no. 3, pp. 673-681, 2005.

[6] M. Marzband, A. Sumper, J. L. Dominguez-Garcia and R. Gumara-Ferret, "Experimental validation of a real time energy management system for microgrids in islanded mode using a local day-ahead electricity market and MINLP" *Energy Conversion and Management*, vol. 76, pp. 314–322, 2013.

[7] Y. H. Chen, S. Y. Lu, Y. R. Chang, T. T. Lee and M. C. Hu, "Economic analysis and optimal energy management models for microgrid systems: A case study in Taiwan" *Applied Energy*, vol. 103, pp. 145–154, 2013.

[8] M. Monadi, M. A. Zamani, J. I. Candela, and P. Rodriguez, "Protection of AC and DC distribution systems embedding distributed energy resources: a comparative review and analysis" *Elsevier J. Renewable and Sustainable Energy Reviews*, vol. 51, pp. 1578–1593, 2015.

[9] J. Shiles et al., "Microgrid protection: An overview of protection strategies in North American microgrid projects" *2017 IEEE Power & Energy Society General Meeting*, Chicago, IL, USA, 2018.

[10] S.F. Zarei, H. Mokhtari and F. Blaabjerg, "Fault Detection and Protection Strategy for Islanded Inverter-Based Microgrids" *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 9, no. 1, February 2021.

[11] D.M. Bui, et al., "Review on protection coordination strategies and development of an effective protection coordination system for DC microgrid" *2015 Asia-Pacific Power and Energy Engineering Conference (APPEEC)*, 2015.

[12] A.A. Sheikh, et al., "A Brief Review on DC Microgrid Protection" *2020 IEEE First International Conference on Smart Technologies for Power, Energy and Control (STPEC)*, 2020.

[13] H. Laaksonen, D. Ishchenko and A. Oudalov , "Adaptive Protection and Microgrid Control Design for Hailuoto Island" *IEEE Transactions on Smart Grid*, vol.5, no.3, May 2014.

[14] B. Liao, J. Cheng and G. Ren , "Microgrid Adaptive Current Instantaneous Trip Protection" *2019 IEEE PES Innovative Smart Grid Technologies Asia*, 2019.

[15] K. Volkov , "Computational Models in Engineering" *IntechOpen*, https://www.intechopen.com/books/computational-models-in-engineering, 2020.

[16] CIGRE , "Benchmark Systems for Network Integration of Renewable and Distributed Energy Resources" *Technical Brochure*,TF C6.04 , 2014.

[17] A. Hazi and G. Hazi, "Overload protection of power lines," 2014 International Conference and Exposition on Electrical and Power Engineering (EPE), 2014, pp. 968-972, doi: 10.1109/ICEPE.2014.6970053.