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Optimal coordination of overcurrent relays in microgrid environments

Andrés R. Herrera-Orozco*; Juan J. Mora-Flórez and Daniela Escobar-Urrea.
Electrical Engineering Program, Universidad Tecnológica de Pereira, Pereira, Colombia.
and
César A. Orozco-Henao.
Dept. of Electrical and Electronic Engineering, Universidad del Norte, Barranquilla, Colombia.

Contents

Source: http://www.millenniumdipr.com/ba-9-sistema-de-control-de-calidad-de-la-publicacion

I. Introduction

Microgrid

Source: https://www.smartgridsinfo.es/comunicaciones/ii-congreso-sg-la-terminacion-inteligente-en-las-smart-grids

Microgrid protection is a challenge

Source: https://es.dreamstime.com

The **coordination strategies that guarantee the correct operation relays** in several fault situations and considering several operating conditions is also a **protection issue.**

II. Basic theoretical aspects

Inverse time overcurrent (ITOC) relays coordination.

IEC 60255 Equation for Trip Time

$$t = \frac{a * TDS}{M^n - 1} \qquad (1)$$

$$M = \frac{i_{fault}}{i_{tap}} \qquad (2)$$

$$i_{tap} = k * i_{max-Load} \qquad (3)$$

Table I: Typical values of shape parameters for IEC parametric curve

Curve type	a	n
Standard inverse time	0.14	0.02
Very inverse	13.5	1
Extremely inverse	80	2
Long inverse time	120	1

III. Analysis of optimization problems of ITOC Relays coordination.

A. Qualitative analysis of objective functions

Objective function 1; [Tjahjono et al., 2017]

$$\min \sum_{i=1}^{N} W_i * t_i^b \tag{4}$$

Objective function 2; [Saberi and Amraee, 2017]-[Albasri et al., 2015]

$$\min \sum_{i=1}^{N} W_i * t_i^p \tag{5}$$

Objective function 3; [Saha et al., 2016]

$$\min \sum_{i=1}^{N} \sum_{j=1}^{M} (t_{ij}^p + t_{ij}^b) * W_i \tag{6}$$

Objective function 4; [Saleh et al., 2016]

$$\min \sum_{i=1}^{N} \sum_{j=1}^{M} \sum_{k=1}^{L} (t_{ijk}^p + \sum_{x=1}^{X} t_{ijk}^{bx}) \tag{7}$$

Objective function 5; [Alam, 2019]

$$\min(\alpha_1 \sum_{i=1}^{N} (t_i^p)^2 + \alpha_2 \sum_{x=1}^{X} (t_x^b - CTI)^2) \tag{8}$$

$$ASOTPBR = \frac{1}{N} \sum_{i=1}^{N} t_i^p + \frac{1}{X} \sum_{x=1}^{X} t_x^b \tag{9}$$

Average sum of the operating times of primary and backup relays (ASOTPBR).

III. Analysis of optimization problems of ITOC Relays coordination.

B. Qualitative analysis of constraints

$$t_x^b - t_i^p \geq CTI_i \quad (10)$$

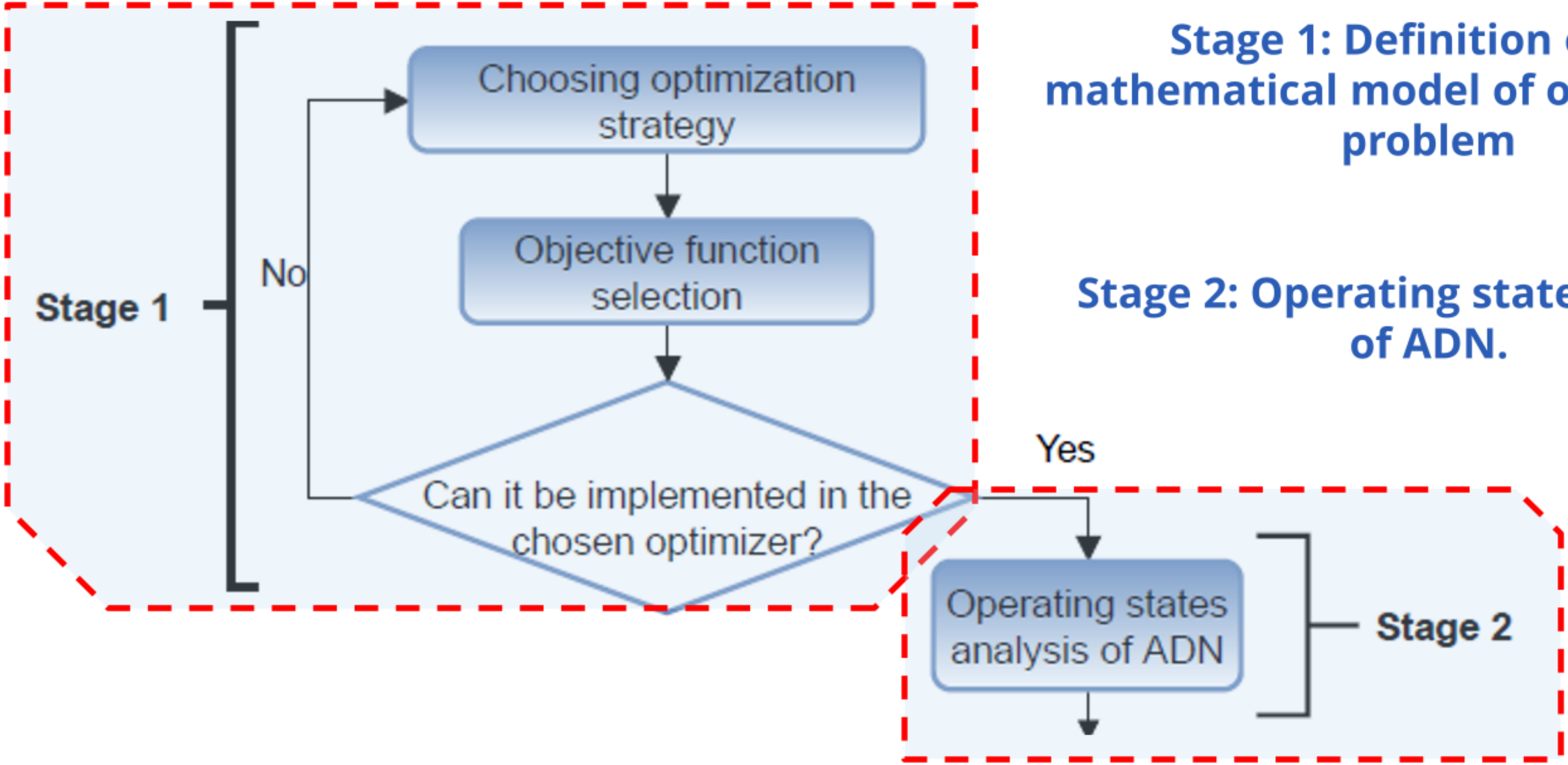
$$t_{x,min} \leq t_x^b \leq t_{x,max} \quad (11)$$

$$TDS_{i,min} \leq TDS_i \leq TDS_{i,max} \quad (12)$$

$$CTI_i \geq CTI_{i,min} \quad (13)$$

Most used restrictions in the literature.

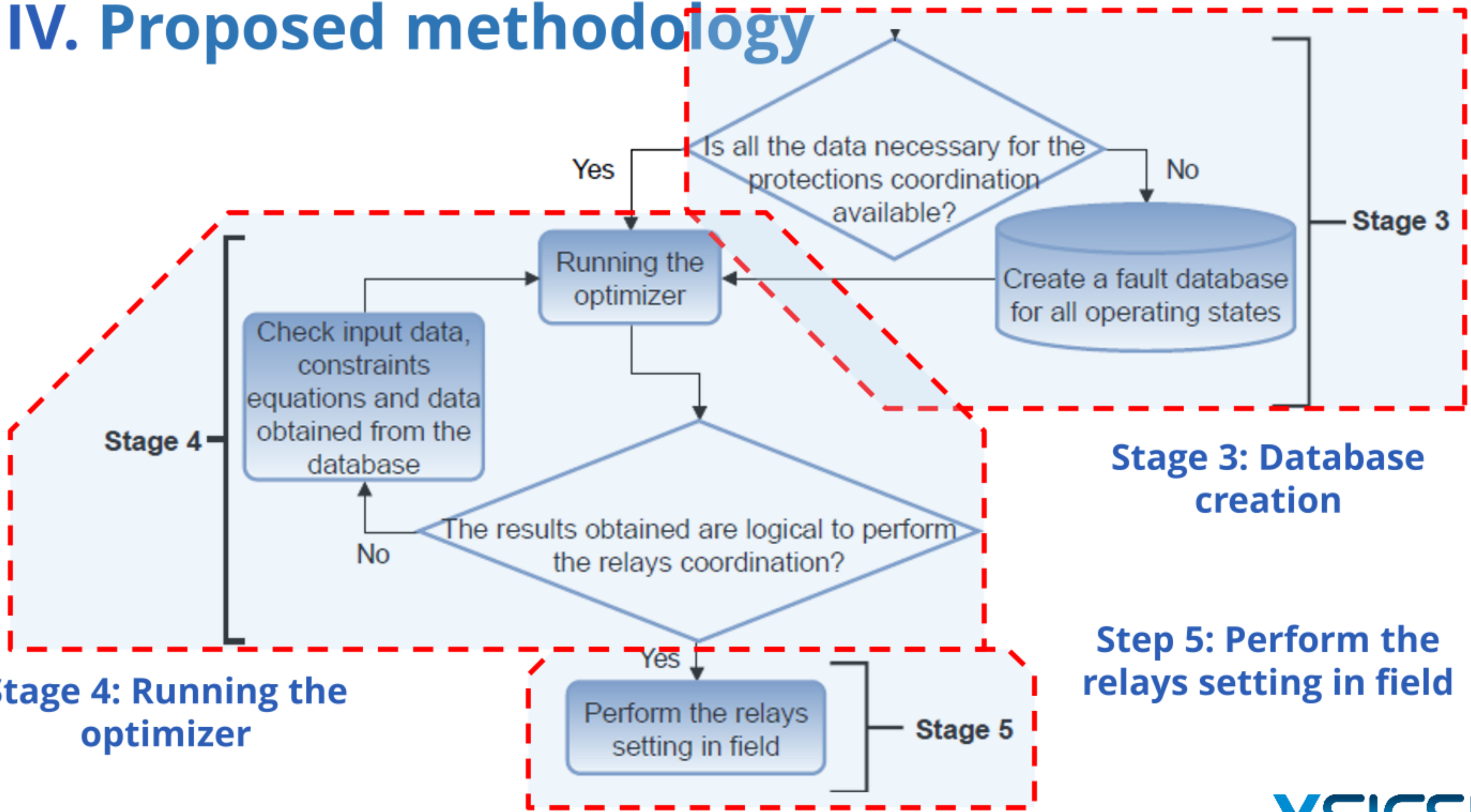
IV. Proposed methodology



Stage 1: Definition of the mathematical model of optimization problem

Stage 2: Operating states analysis of ADN.

IV. Proposed methodology



Stage 3: Database creation

Stage 4: Running the optimizer

Step 5: Perform the relays setting in field

V. Methodology application, results and analysis

A. Case study

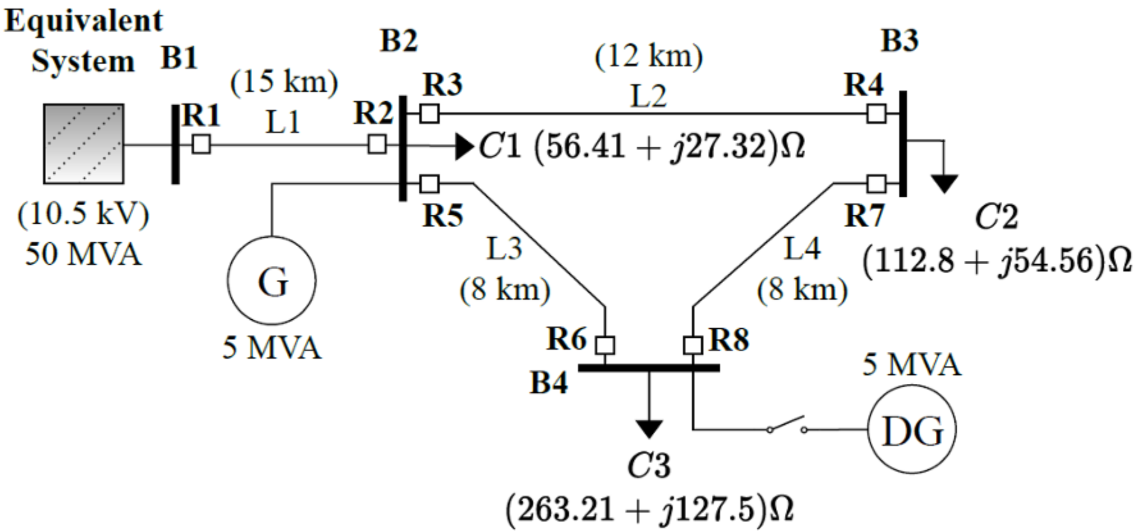


Fig 2. ADN selected for case study; source [Alam, 2019]

Table II: Lines parameters data in sequence components

Sequence	Value	Units
R0	0.5868094	Ω/km
L0	1.306735	Ω/km
C0	1.918928524	$\mu\mho/km$
R+	0.2364925	Ω/km
L+	0.4170011	Ω/km
C+	4.002092474	$\mu\mho/km$

V. Methodology application, results and analysis

B. Definition of the optimization problem

Objective function 2; [Saberi and Amraee, 2017]-[Albasri et al., 2015]

$$\min \sum_{i=1}^{N} W_i * t_i^p \qquad (5)$$

S.t.

$$t_x^b - t_i^p \geq CTI_i \qquad (14)$$

$$TDS_i \geq TDS_{i,min} \qquad (15)$$

$$t_i - h_i * TDS_i \geq 0 \qquad (16)$$

$$h_i = \frac{a}{M^n - 1} \qquad (17)$$

Objective function 5; [Alam, 2019]

$$\min(\alpha_1 \sum_{i=1}^{N} (t_i^p)^2 + \alpha_2 \sum_{x=1}^{X} (t_x^b - CTI)^2) \qquad (8)$$

$$ASOTPBR = \frac{1}{N} \sum_{i=1}^{N} t_i^p + \frac{1}{X} \sum_{x=1}^{X} t_x^b \qquad (9)$$

$$\alpha_1 = 0.73 \qquad \alpha_2 = 0.27$$

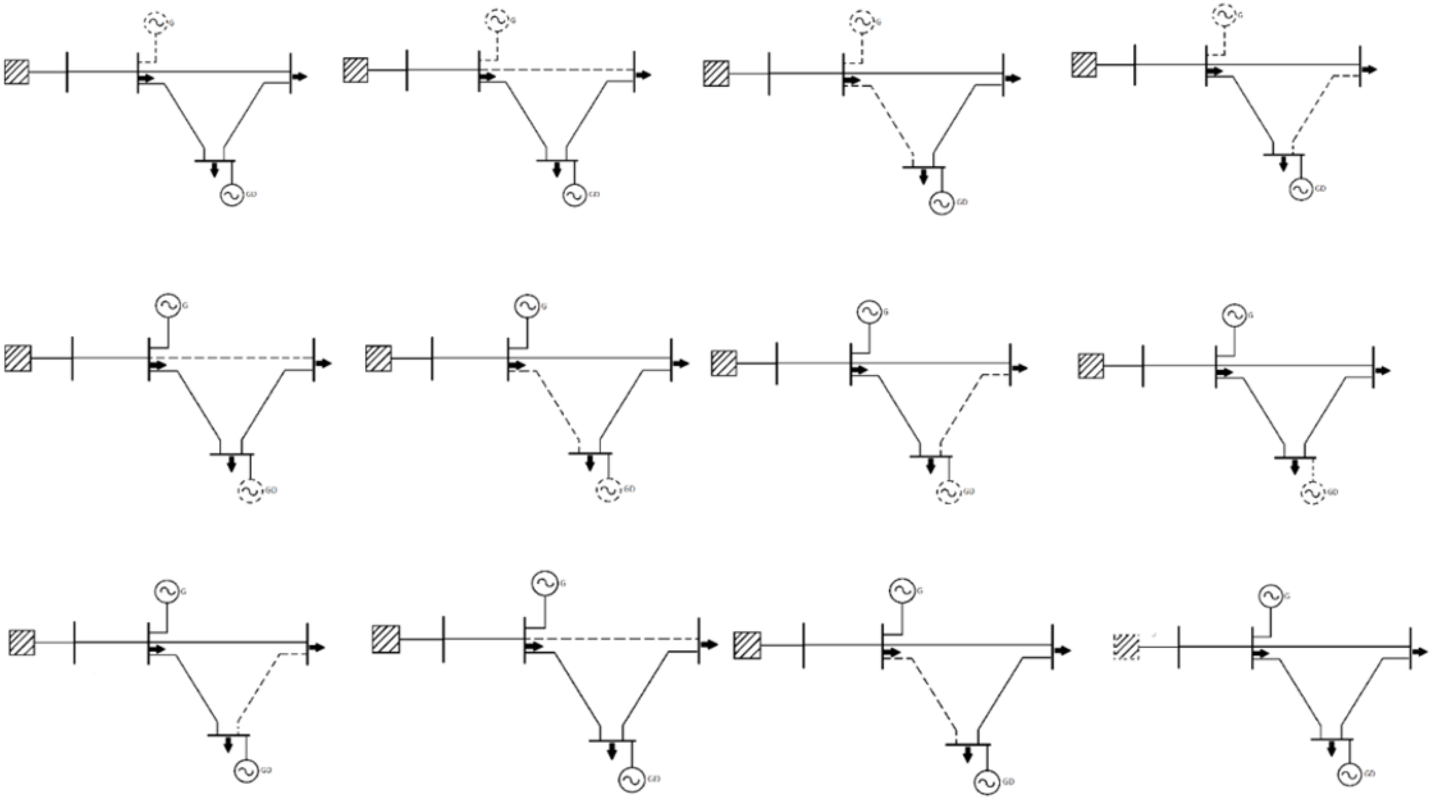
IEC 60255 standard inverse time curve

$$a = 0.14 \qquad n = 0.02$$

MINOS solver was chosen

V. Methodology application, results and analysis

C. Operating states analysis



The first operating state is the system under normal conditions (all generators, lines, and loads connected in the system)

V. Methodology application, results and analysis

D. Database creation

Table III: Data obtained from the simulation of normal operating state

Relay	$i_{max-Load}$	i_{tap}	$i_{local-fault}$	$i_{remote-fault}$
1	41.0524	61.5786	6353.8281	891.3418
2	41.1603	61.7405	1823.7320	645.1878
3	7.2102	10.8153	2473.4116	679.9707
4	7.3106	10.9659	815.5225	216.8145
5	2.9457	4.4186	2149.7376	795.4331
6	2.7738	4.1607	1369.9880	544.4038
7	9.9886	14.9829	686.0947	316.8082
8	9.8657	14.7986	1842.1251	813.2366

V. Methodology application, results and analysis

E. Running the optimizer

Table IV: Relays adjustment obtained from normal operating state considering (5) and (8) objectives functions

Relay	Local fault time (s)	Remote fault time (s)	TDS
1	0.534	0.945	0.371
2	0.200	0.291	0.100
3	0.732	0.973	0.600
4	0.646	0.945	0.415
5	0.745	0.897	0.701
6	0.776	0.932	0.682
7	0.773	0.976	0.439
8	0.697	0.846	0.504

Table V: Relays adjustment obtained from all operating states considering (5) and (8) objectives functions

Relay	Local fault time (s)	Remote fault time (s)	TDS
1	5.033	7.917	3.073
2	2.362	3.366	0.499
3	9.073	12.947	4.252
4	1.332	2.953	1.297
5	5.708	7.217	2.591
6	5.982	7.066	2.906
7	17.288	22.144	6.624
8	4.578	5.287	2.253

V. Methodology application, results and analysis

E. Running the optimizer

Table VI: Relays adjustment obtained from the operating states considering only contingencies N-1 for the (5) and (8) objectives functions

	Objective function (5)			Objective function (8)		
Relay	Local fault time (s)	Remote fault time (s)	TDS	Local fault time (s)	Remote fault time (s)	TDS
1	2.720	4.278	1.661	1.442	2.268	0.881
2	0.474	0.675	0.100	0.858	1.222	0.181
3	3.064	4.372	1.436	3.064	4.372	1.436
4	1.332	2.953	1.297	1.234	1.094	0.480
5	5.708	7.217	2.591	1.852	2.342	0.841
6	1.421	2.201	0.905	1.421	2.201	0.905
7	5.599	7.172	2.145	5.599	7.172	2.145
8	4.578	5.287	2.253	1.858	2.146	0.914

VI. Conclusions

- A general methodology to obtain global relays settings and which guarantees the correct coordination of them is proposed.
- This approach considers the ADN operating states which has the highest probability of occurrence.
- Additionally, the proposal seeks to avoid the cost associated with communication systems and makes the relay adjustment as simple as possible since a single relay configuration would be enough for all valid operating states.
- Two functions were suggested and analyzed. The results show the potential of the proposal for real-life application.

VII. Questions

Source: https://es.fotolia.com/Fotolia_42267434_Subscription_XXL.jpg