Wide area blackout in Colombian power system due to a three phase fault on a busbar - Lessons learned for protection criteria

J. Castano, J. Velez, M. N. Arboleda, and J. A. Zapata

***Abstract*— On November 17th, 2012 at 14:52 there was system disturbance in the north coast of Colombia – provinces of Bolivar and Atlantico that caused a demand unserved of 325 MW (38 % of the demand of the area) and a generation loss of 82 MW (12 % of the generation of the area). The disturbance was a three-phase fault in a 220 kV busbar where the misoperation of busbar differential protection generated a cascading event. Some electric characteristics of the zone as short lines and large thermal units prompted further analysis of angular stability to identify improvements in the involved protection schemes. As result, important recommendations in current protection schemes were found. Those improvements include change and duplicity of busbar differential protections as well as redundancy in teleprotection schemes associated with transmission lines. Additionally, potential improvements can be achieved by design and implement System Integrity Protection Schemes (SIPS) to avoid cascade events when main protections of lines or busbar are not available. This is particularly important in those points of the grid were critical clearing times are shorter that operating times of local or remote backup protections.**

To develop this work, the following tasks were performed: detailed analysis of the disturbance and the protection systems performance, analysis of zone 2 reaches of the transmission lines distance protections, determination of critical clearing times for faults in busbars and transmission lines and determination of recommendations for improvements in current protection schemes.

***Index Terms*— Blackout, disturbance analysis, protection misoperation, power system protection, stability studies.**

I. Introduction

On November 17th, 2012 at 14:52 there was system disturbance in the North coast of Colombia – Provinces of Bolívar and Atlántico (Fig. 1) that caused a demand unserved of 325 MW (38 % of the demand of the area) and a generation lost of 82 MW (12 % of the generation of the area). The following chapters describe the analysis of the event and the task subsequently executed in order to identify and minimize risks that current protection schemes can represent for the system.

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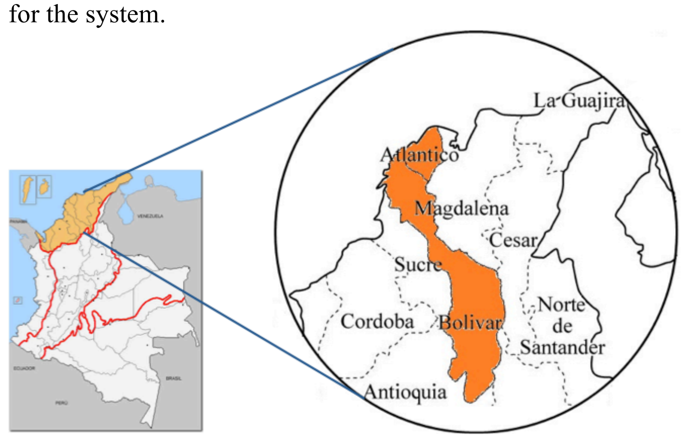

Fig. 1. Provinces affected by the disturbance.

II. Description of the Disturbance

The following is the entire sequence of events derived from the oscillographic records and the protection system performance (see Fig. 2):

1) Phase-to-phase fault in Line 2B 220 kV at the end corresponding to Substation A. The fault was due to the detachment of one of the porch isolators of Line 2B (phase C) that falls over phases B and C of the busbar. Then, the event evolves to a three-phase fault.
2) The fallen isolator causes a derivation path for the primary winding of the CT of Line 2B.
3) Misoperation of busbar differential protection (87B), which did not operate within a fault in its protection zone.
4) Misoperation of differential protection of Line 2B 220 kV (87L), which tripped single-phase in both ends of the line, for a phase-to-phase fault.
5) Misoperation of Breaker Failure Schemes located at Substation B, which causes undesirable disconnection of Line 3B and Line 2B 220 kV at substation B.
6) Distance protections of line 10 66 kV at substation C, line 11 66 kV at substation C, line 12 66 kV at substation C, line 13 66 kV at substation H, trips due to the voltage

depression caused by the fault in Substation A 220 kV.

7) Distance protection of line 6 220 kV at substation F, trips in Zone 2 due to the fault in substation A 220 kV, causing an undesirable disconnection of this line by zone-2 overeaching.
8) Distance protection of line 2A 220 kV at substation B, and line 1 220 kV at substation D, trips correctly by Zone 2.
9) The fault is finally cleared after 479 ms.

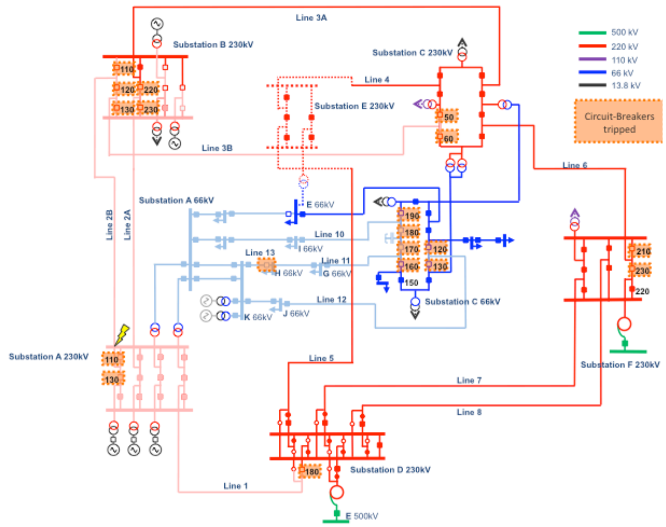

Fig. 2. One-line diagram.

III. Further Analysis

After the analysis of the event, the following tasks should be executed in order to identify the risks associated to a misoperation of a bus differential protection:

1) Evaluation of zone-2 settings in distance relays.
2) Determination of critical clearing times under faults in busbars.
3) Determination of critical clearing times under faults in transmission lines.

IV. Evaluation of Zone-2 Settings in Distance Relays

Table 1 shows a summary of settings revision of distance relays (zones 2) in the lines under study. This table contains electrical parameters of each line, current settings of zone-2 and a calculation of the percentage of reaching. This percentage is presented based in the length of line analyzed as well as in the length of shorter adjacent line.

TABLE I
ZONE-2 SETTINGS EVALUATION

Line	Lenght km	Lenght R1 Ω pri	Lenght X1 Ω pri	Lenght Z1 Ω pri	Adjacent Shorter Line (ASL)	Lenght km	Lenght R1 Ω pri	Lenght X1 Ω pri	Lenght Z1 Ω pri	RTC	RPT	Zone 2 Settings Ω sec	Zone 2 Settings Ω pri	Overeach *	Overeach (ASL)**	Time [ms]
Line 1 (end 1)	18,30	1,15	8,99	9,06	Line 2 (end 1)	2,88	0,26	1,43	1,46	800	2000	4,22	10,55	17%	109%	400
Line 2 (end 1)	2,88	0,26	1,43	1,46	Line 2 (end 2)	2,88	0,26	1,43	1,46	320	2000	0,33	2,06	44%	44%	250
Line 3 (end 1)	3,12	0,28	1,55	1,57	Line 3 (end 2)	3,12	0,28	1,55	1,57	240	2000	0,31	2,58	67%	67%	250
Line 4 (end 1)	25,69	1,66	11,66	11,77	Line 5 (end 1)	16,85	1,02	7,54	7,61	200	2000	1,56	15,64	34%	53%	400
Line 5 (end 1)	16,85	1,02	7,54	7,61	Line 1 (end 1)	18,30	1,15	8,99	9,06	2500	1913	15,79	12,08	60%	51%	400
Line 6 (end 1)	80,18	7,16	39,77	40,41	Line 9	38,42	3,45	19,06	19,37	200	2000	6,00	60,00	51%	106%	400
Line 7 (end 1)	69,91	6,24	34,68	35,23	Line 5 (end 2)	16,85	1,02	7,54	7,61	1000	2000	23,22	46,44	34%	156%	400
Line 8 (end 1)	63,21	3,98	31,48	31,73	Line 5 (end 2)	16,85	1,02	7,54	7,61	1000	2000	21,17	42,33	34%	144%	400
Line 6 (end 2)	80,18	7,16	39,77	40,41	Line 3 (end 2)	3,12	0,28	1,55	1,57	1000	2000	25,73	51,46	29%	756%	400
Line 5 (end 2)	16,85	1,02	7,54	7,61	Line 4 (end 2)	25,69	1,66	11,66	11,77	800	2000	3,93	9,84	30%	20%	400
Line 4 (end 2)	25,69	1,66	11,66	11,77	Line 3 (end 2)	3,12	0,28	1,55	1,57	2500	1913	18,56	14,20	22%	165%	400
Line 3 (end 2)	3,12	0,28	1,55	1,57	Line 2 (end 2)	2,88	0,26	1,43	1,46	200	1913	0,22	2,10	36%	39%	250
Line 2 (end 2)	2,88	0,26	1,43	1,46	Line 2 (end 2)	2,88	0,26	1,43	1,46	240	2000	0,25	2,08	45%	45%	250
Line 1 (end 2)	18,30	1,15	8,99	9,06	Line 5 (end 2)	16,85	1,02	7,54	7,61	1600	2000	9,60	12,00	34%	40%	400
Line 7 (end 2)	69,91	6,24	34,68	35,23	Line 9	38,42	3,45	19,06	19,37	800	2000	19,68	49,20	42%	76%	400
Line 8 (end 2)	63,21	3,98	31,48	31,73	Line 9	38,42	3,45	19,06	19,37	800	2000	17,20	43,00	37%	60%	400

* This percentage is calculated based on the lenght of the line under analysis
** This percentage is calculated based on the lenght of the adjacent shorter line

A. Results

A square in yellow in table 1, shows a risk of under-reaching when classic criterion for zone-2 protection is applied: zone-2 must cover al least 120% of the line impedance in order to ensure a complete coverage of faults along the line. This reach must take into account the inaccuracies of transducers (PT's and CT's).

Squares in red shows risks of zone-2 over-reaching due to the total coverage of all the impedance of the adjacent shorter line. In this cases loss of selectivity can appear due to overlapping of zones-2.

Regarding to the time delays of zones-2, squares in green denote proper stepped-distance operation. A red square indicates times that have to be modified in order to find coordinated operations of overlapped zones-2.

V. Determination of Critical Clearing Times for Faults in Busbars

It was done using the Stability module of DigSilent Power Factory, taking into account the following assumptions:

-- The grid shown in figure 1 all in service.
--180 MW of power in Substation A.
--314 MW of power in Substation B.
--Loads according to a low-demand scenario.
--Simulation of solid 3-phase faults at each busbar.
--Measurement of rotor angle of each generator with respect to the rotor angle of the reference machine (firel parameter in DigSilent software).
--Non-disconnection of any element in the grid under study.
--1 s of time simulation.
--Automatic controls of generators out of service.

A. Results

TABLE II
CRITICAL CLEARING TIMES FOR FAULTS IN BUSBARS

Substation	Critical clearing time [ms]	First generator out of synchronism
Substation A	250	Substation A
Substation B	150	Substation A
Substation C	200	Substation A
Substation D	150	Substation A
Substation E	300	Substation B
Substation F*	<200	

* Critical clearing time is given for a generator out of the area illustrated in Fig. 1.

As all critical clearing times are below of 300 ms, the distance protections installed at remote ends of the faulted bus cannot provide proper backup operation times keeping the stability of the system. Careful maintenance activities were recommended for the busbar protection scheme and the implementation of redundancy to increase it reliability.

The critical clearing times obtained also shown that under-reaches of zones 2 in distance relays could compromise the angular stability of the system. Based on this, a detailed validation of current zone 2 setting should be performed considering stepped coordination required under overlapping conditions of this zones.

Under classical non-redundant busbar protection schemes, a misoperation of differential protection can compromise the stability of the system and consequently can be produce cascading events or blackouts. It mainly happens when it occurs in busbars that are close to big generators.

Critical clearing times below of zones-2 time delays, makes advisable special attention to reliability of protection schemes with detailed analysis of possible improvements in terms of the implementation of redundancy.

VI. Determination of Critical Clearing Times for Faults in Lines

Under previous assumptions for the simulations of faults in busbars, critical clearing times were determined for three-phase solid faults at each end of the lines analyzed. 100 ms was the operation time assumed for the closer breaker to the fault. Results are shown in table 3.

A. Results

TABLE III
CRITICAL CLEARING TIMES FOR FAULTS IN LINES

Three-phase fault at 1% of the lenght of the line	Maximum operating time of remote end to maintain sincronism [ms]	First generator out-of-step
Line 2 (end 1)	200	Substation A
Line 2 (end 2)	200	Substation A
Line 3 (end 1)	200	Substation A
Line 3 (end 2)	200	Substation A
Line 4 (end 1)	> 1000	Substation B
Line 4 (end 2)	600	Substation B
Line 6 (end 1)	> 5000	-
Line 6 (end 2)	> 1000	Substation B
Line 5 (end 1)	600	Substation B
Line 5 (end 2)	850	Substation B
Line 1 (end 2)	500	Substation B
Line 1 (end 1)	350	Substation B
Line 7 (end 2)	> 5000	-
Line 7 (end 1)	> 1000	Substation B

Five of the thirteen lines analyzed has critical clearing times below of classical zone 2 time delay settings which can be a risk for the stability of the nearest generators. Special attention is advisable for the main protections of those lines and redundancy in their protections schemes if necessary.

VII. Conclusion

For balanced faults in lines and busbars, backup protection operating times are in some cases not enough to keep the stability of the system. It usually occurs close to generators. This is particularly important to consider when a busbar differential protection misoperates in a presence of faults. In those cases redundancy in main protection schemes is required. System Integrity Protection Schemes (SIPS) can be useful to avoid cascade events when main line or busbar protections are not available.

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