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STATCOM Effect on Voltage Profile of a Distributed Network Considering Two Different Measurement Positions

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Abstract. The voltage profile of low voltage distribution systems must be in accordance to national regulations, usually given by a range in which voltage needs to be. Along a day, usually voltage fluctuates according to load characteristics, especially power level and power factor, and in some situations can overpass minimum acceptable values. This paper studies the influence of the power factor measurement point governing a D-STATCOM, over the feeder voltage profile. By simulation, it was saw that connecting the D-STATCOM at the end of the system, but correcting power factor saw by the initial pole, a better voltage compliance is obtained.

Keywords. D-STATCOM, voltage profile, fuzzy control, power factor, power quality.

1. Introduction

For medium and high voltage transmission and distribution systems, the capacitor placement at the line is a common solution to recover the voltage profile back to normative limits. The practice has also been applied to low voltage distribution systems, attempting to their specific trade-offs [1-5], such as unaccepted voltage drop or line losses reduction.

A better behaviour was achieved incorporating power electronics solutions to power systems, being at transmission or distribution level [6-9].

STATic COMpensators applied to distribution systems are graphed as D-STATCOM, and many studies are constantly published also concerning low voltage systems, single and three-phase applications [10-14] – LV D-STATCOM.

STATCOM is usually controlled by measurements done in its front end – grid voltage and current at its connection point.

As the world is walking towards an integrated solution, in what smart cities take a look over all the included system in it and not only at a particular point, a question arises about the LV D-STATCOM control, concerning where measurements should be performed.

In this aspect, this paper realizes a simulation study exploring the voltage profile along a five-pole LV distribution system – as Figure 1

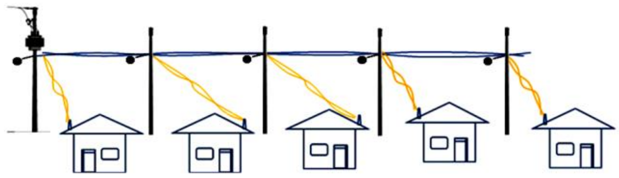


Fig. 1 – Visualization of the five-pole LV distribution system.

The LV D-STATCOM, presenting a specific function of power factor control, is connected at the end of a radial LV distribution line. Two situations are analysed: one, the measurement point being the connection point itself; other, measurements being done in the transformer connection point.

2. System Description

A STATCOM has as a common application the power factor correction. In this task, it operates as a variable reactance, according to the load behaviour. In simple words, it can be an adjustable capacitor in order to improve power factor of an inductive load, or an inductor if the load current is capacitive.

The basic structure of the STATCOM implementation in this study is presented in Figure 2. Voltage and current at the connection point are measured, and power factor is calculated. Information is sent to the power factor logic control, which gives the index modulation (m_a) as well as the synchronization angle, to be applied to the PWM control block.

The DC-AC converter delivers a fundamental voltage aligned to the voltage at the connection point. If both voltages are equal, no correction action occurs. When the produced voltage is greater than voltage at the connection point, the STATCOM acts as a capacitor, otherwise operates as an inductor.

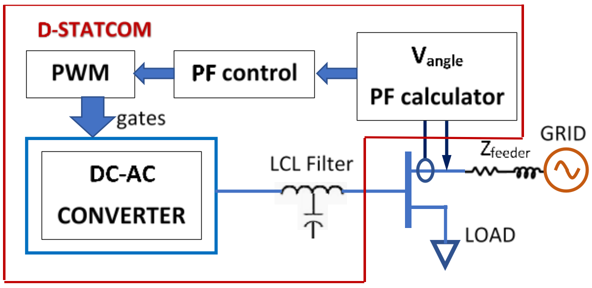


Fig. 2 – Basic diagram of the STATCOM implemented.

A variety of power electronics topologies can be found serving as STATCOM, since classical full-bridge inverters (single and three-phase ones) till multilevel topologies. Even in single-phase applications, synthetization of a few levels is considered a possible improvement [15-17]. In sake of simplicity for the authors, due to its extensive use in several own studies, a five-level DC-AC topology is considered in the simulation [18].

In this paper, the analysis is carried out considering a small distribution system, although can be easily extended to any. As, in a residential feeder, majority of loads are phase-to-neutral connected, it is considered the per-phase circuit, and a single-phase STATCOM. An equivalent electric circuit is shown in Figure 3, whereas details of the five-pole distribution system as well as pole loads are given in Table 1. P1 is the pole with transformer, and in sequence left to right, the others are P2 to P5.

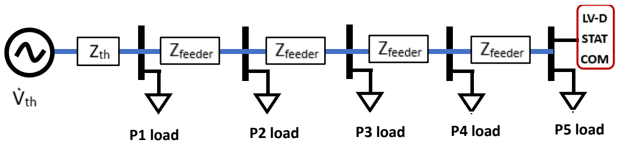


Fig. 3 – Simulated equivalent circuit of the distribution system.

Table I

V_{th}	127	V, rms
Z_{th}	0.5 + j2	ohms
Z_{feeder}	0.02 + j0.015	ohms
Loads P1 to P4*	2.6 + j1.9	ohms
	600 W	rectifier

*Initial allocation

3. The Fuzzy Controller

Besides the variety of topologies that can be found as a LV D-STATCOM equipment, an enormous quantity of control approaches governing a STATCOM is continuously being presented. Among them, fuzzy control has been revealed as an attrahent option considering its fast response [19-21].

In this way, a fuzzy logic controller is employed here in the power factor control loop. The fuzzy inference system (FIS) used was the Mamdani method, widely recognized as a powerful approach for capturing expert knowledge.

The input variables for the fuzzy control block are the reactive power (E_r), the power factor (pf), and previous modulation index (m_a). The reactive power is calculated every line period, and used to calculate the power factor. After some simulations, it was noticed that the system was more sensitive for light loads, presenting greater variations in the power factor for the same variation of the modulation index when the power of the loads was lower. For this reason, the sets created for the reactive energy are narrower close to zero, as shown in Figure 4.

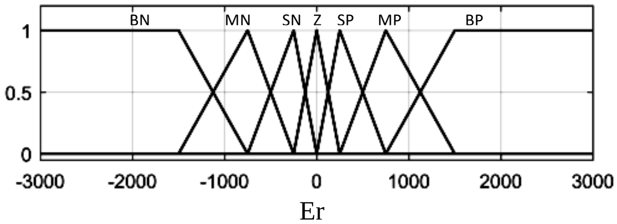


Fig. 4 – Reactive power membership functions.

Where BN is Big Negative, MN Medium Negative, SN Small Negative, Z is Zero, SP is Samll Positive, MP Medium Positive, and BP Big Positive.

Power factor is also obtained each line period, and its membership functions are shown in Figure 5. Considering current Brazilian standard, the objective was to keep pf above 0.92.

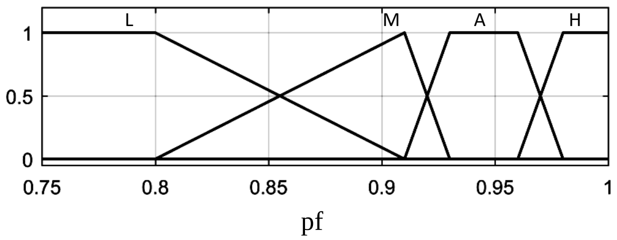


Fig. 5 – pf membership functions.

Here, L is Low, M is Medium, A is adequate, and H means High.

The last input is the current modulation index, and its respective fuzzy set is presented in Figure 6.

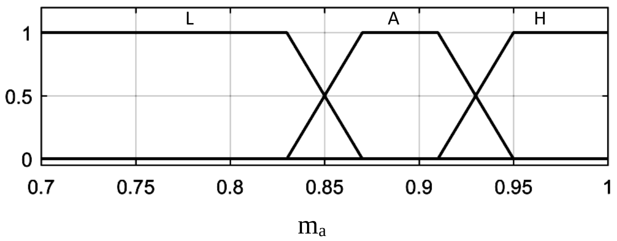


Fig. 6 – Modulation index fuzzification.

The fuzzy controller output is the modulation index variation, Δm_a, to be added to the previous modulation index, and its defuzzification rules are shown in Figure 7.

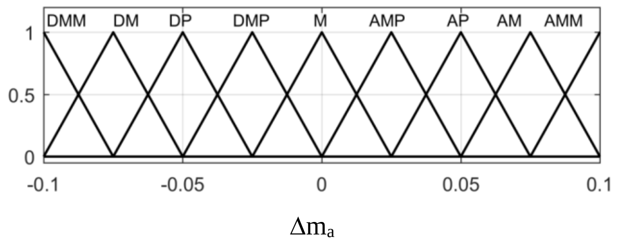


Fig. 7 - Δm_a defuzzification rules.

Table II contains the defuzzification rule base.

Table II. Rule base of Mamdani-type FIS

Rule number	INPUTS			OUTPUT
	m_a	pf	E_r	Δm_a
1	-	L	BN	DMM
2	-	L	MN	DP
3	-	L	SN	DMP
4	-	L	Z	M
5	-	L	SP	AMP
6	-	L	MP	AP
7	-	L	BP	AMM
8	-	M	BN	DM
9	-	M	MN	DP
10	-	M	SN	DMP
11	-	M	Z	M
12	-	M	SP	AMP
13	-	M	MP	AP
14	-	M	BP	AM
15	-	A	-	M
16	L	H	BN	AP
17	L	H	MN	AP
18	L	H	SN	AMP
19	L	H	Z	AMP
20	L	H	SP	AP
21	L	H	MP	A
22	L	H	BP	AMM
23	A	H	-	M
24	H	H	BN	DP
25	H	H	MN	DP
26	H	H	SN	DMP
27	H	H	Z	DMP
28	H	H	SP	DP
29	H	H	MP	DM
30	H	H	BP	DMM

4. Simulation Results

For all simulations here presented, the STATCOM is fixed at final pole (pole 5), and two conditions were considered: measurements realized at pole 5 (line end), and also at line start (pole 1). In order to explore operation considering load changes, a simulation time of 7.5 seconds were selected. Simulations where initially performed considering a situation of constant load on poles 1 to 4 – see Table I. The load applied to pole 5 changes accordingly to the Table II.

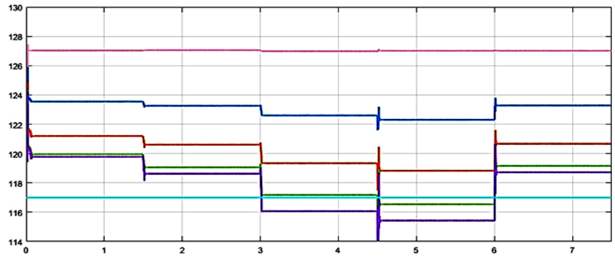
Table II – variable load

constant	600 W	rectifier
constant	13.2	ohms
1.5 to 3 s	2.6 - j1.9	ohms
3 to 4.5 s	3.6 + j1.9	ohms
4.5 to 6 s	7500 W	rectifier
6 s and after	8.1 + j8.1	ohms

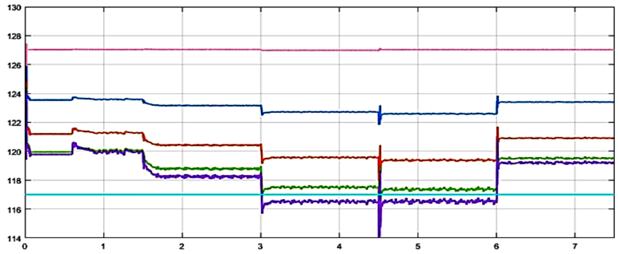
The evolution of the voltage profile respect load changes, with no STATCOM, is presented in Figure 8 – (a). The colors are associated to poles as follows: yellow – pole 1; blue – pole 2; red – pole 3; green – pole 4; purple – pole 5 (STATCOM place). The light blue line is the lower allowed value for phase-to-neutral voltage in part of Brazil. One can observe that poles 4 and 5, in some situations, have voltage values out of limits.

Figure 8 – (b) contains the voltage profile with the D-SATCOM operation. The power factor is derived at the own connection point. In this situation, pole 4 attends the acceptable minimum voltage value, but pole 5 still remains on under voltage operation.

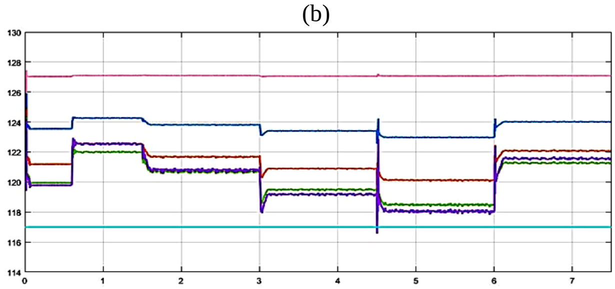
On the other hand, in this analysis, if the power factor is measured just in the LV front-end of the transformer (pole 1), all voltages are within limits, as can be seen in Figure 8 – (c).



(a)



(b)

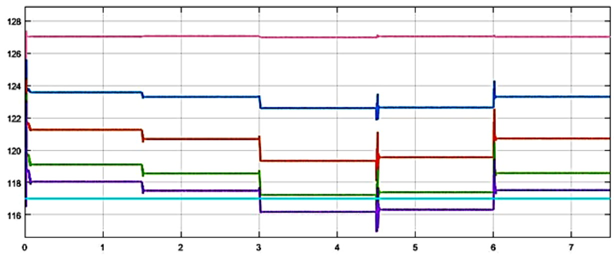


(c)

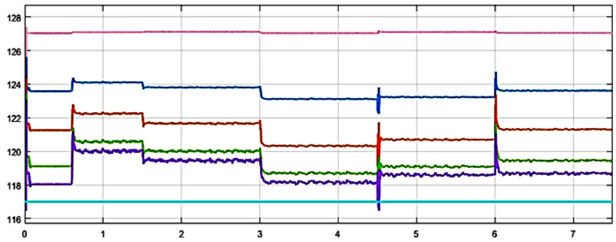
Fig. 8 – Voltage profile on poles 1 to 5, variable load on pole 5: (a) Without STATCOM; (b) STATCOM controlled by pole 5 measurements; (c) STATCOM controlled by pole 1 measurements (pink – pole 1; blue – pole 2; red – pole 3; green – pole 4; purple – pole 5). light blue: minimum standard rms voltage value. Axis: y: Volts; x: seconds.

In order to verify the variable load connection position influence on the voltage profile, two other configurations where simulated. In the first one, the constant loads presented in Table I were connected to poles 1, 2, 4 and 5; and the variable load was connected to pole 3.

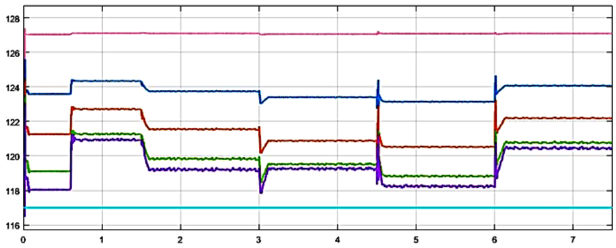
The Figure 9 contains the pole voltages with this arrangement. Figure 9.a has the pole voltages without any compensation. It can be observed that voltage in the last pole (P5) is out of valid value. The others are above the lower limit. If the power factor is obtained at the D-STATCOM connection, pole P5, all voltages are within standard, Figure 9.b. The same compliance occurs doing measurements at pole 1, Figure 9.c.



(a)



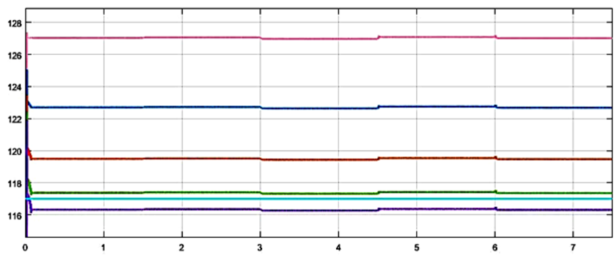
(b)



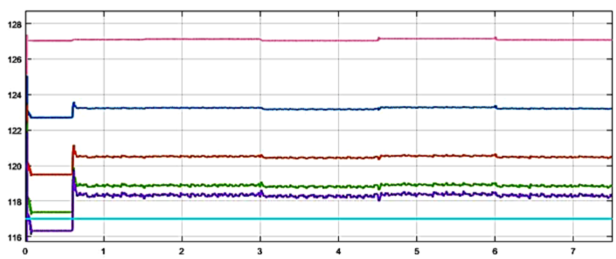
(c)

Fig. 9 – Voltage profile on poles 1 to 5, variable load connected at pole 3: (a) Without STATCOM; (b) STATCOM controlled by pole 5 measurements; (c) STATCOM controlled by pole 1 measurements (pink – pole 1; blue – pole 2; red – pole 3; green – pole 4; purple – pole 5). light blue: minimum standard rms voltage value. Axis: y: Volts; x: seconds.

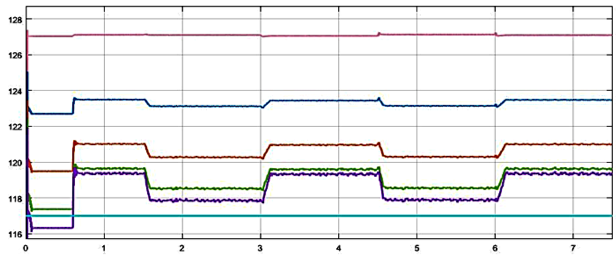
To complete, fixed loads were connected to poles 2 to five, and variable load connected to pole 1. Voltage results on poles 1-5 are shown in Figure 10: (a), with no compensation; (b) considering the power factor measured at pole 5; and (c), getting the power factor at pole 1. From Fig. 10.a, the pole 5 presents voltages under lower standard limit. Connecting the D-STATCOM, all poles went into voltage compliance, no matter the pf measurement position.



(a)



(b)



(c)

Fig. 10 - Voltage profile on poles 1 to 5, variable load connected at pole 1: (a) Without STATCOM; (b) STATCOM controlled by pole 5 measurements; (c) STATCOM controlled by pole 1 measurements (pink – pole 1; blue – pole 2; red – pole 3; green – pole 4; purple – pole 5). light blue: minimum standard rms voltage value. Axis: y: Volts; x: seconds.

5. Conclusion

Using STATCOM in LV distribution systems allows to improve voltage profile. If the D-STATCOM is operating regulating power factor, simulations presented here show that the measurement point has an important influence over voltage profile along the feeder.

The best point to control the power factor is the transformer front end, as could be observed in the simulation results. In the analysis carried out, this position led to total voltage compliance in all configurations. Meanwhile, in some situations the measurement point being at the D-STATCOM connection, the voltages behaviour presented less discrepancy respect load changes.

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