

Short-Circuit Current Mitigation in MV Distribution Network Using DSTATCOM: Modeling and Simulation

Ousseyni Ibrahim Hassane¹, Ali Souley Issa², Arouna Oloulade³

¹Department of Electrical Engineering, Dan Dicko Dan Koulolo University of Maradi, Maradi, Niger

²Faculty of Science and Technology, Department of Physics, Dan Dicko Dan Koulolo University of Maradi, Maradi, Niger

³LETIA, University of Abomey-Calavi, Cotonou, Benin

Email: hassane2025@yadoo.fr, alisouleyissa01@gmail.com, olouarou@yahoo.fr

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Abstract

MV distribution networks are exposed to various types of short-circuit faults generating high currents that can affect stability, power quality, and equipment safety. This article presents an in-depth analysis of short-circuit current behavior in an MV distribution network incorporating a shunt-type static reactive power compensator (DSTATCOM). Using simulations performed in MATLAB/Simulink, the impact of the DSTATCOM is evaluated for single-phase, two-phase, and three-phase faults. The results obtained demonstrate a significant reduction in fault current amplitudes, mitigation of voltage sags, and overall improvement in network stability.

Keywords

DSTATCOM, Short-Circuit, MV Distribution Network, FACTS, Power Quality, MATLAB/Simulink

1. Introduction

Conventional compensation systems, such as capacitor banks, mechanically controlled reactors, and synchronous machines, have long been used to increase steady-state power transfer by regulating voltage in distribution networks in a conventional manner [1] [2]. Today, the rapid development of power electronics has enabled the emergence of new equipment and advanced methods for power flow control, voltage regulation, transient stability improvement, and damping of electromechanical oscillations in electrical networks [3]. These devices, known as Flexible AC Transmission Systems (FACTS), based on advanced power elec-

tronics technologies, provide technical solutions adapted to new network operation constraints [4] [5]. These static devices have made shunt reactive power compensation flexible. Among them, the STATCOM, a static synchronous compensator used in transmission networks, exhibits functional behavior comparable to that of a synchronous machine, while eliminating constraints related to mechanical inertia [6]. Similarly, the DSTATCOM, a component from this family, is power electronics equipment using a voltage source converter that can be connected in shunt to the distribution network and whose purpose is to inject capacitive or inductive current to compensate and control electrical quantities in distribution networks [7] [8]. In the context of reactive power compensation and voltage regulation in distribution networks, R. Madhusudan and al [9] modeled and simulated a DSTATCOM for power quality problems (voltage sags and swells) based on sinusoidal pulse width modulation (SPWM). M. Kumar and al [10] designed and operated a DSTATCOM for improving power quality in electrical distribution networks. G. Gupta and al [11], conducted a comprehensive review of DSTATCOM network control and compensation strategies. C. Chodavadiya and al [12] combined DSTATCOM and DVR to improve the voltage profile of an electrical distribution network. In an electrical network incorporating a DSTATCOM compensation device, the effect of short-circuits can be either mitigated or, in certain cases, result in a modification of the system's electromagnetic dynamics. The behavior of the DSTATCOM in the face of single-phase, two-phase, and three-phase faults depends closely on the network's inherent characteristics as well as the fault location. Short-circuits constitute one of the main sources of power quality degradation, particularly voltage sags, voltage variations, and harmonic distortions, affecting power transfer and reactive power exchanges [13].

In this article, the DSTATCOM model is simulated using a control strategy based on pulse width modulation (PWM) combined with a PID controller to reduce fault current oscillations, which constitute one of the most severe disturbances in the distribution network. Simulations were performed in MATLAB/Simulink to validate the device's effectiveness and compare network performance with and without D-STATCOM.

2. Description of the Distribution Network under Study

Electrical distribution networks, as the final link in the supply chain, ensure energy delivery from the transmission network to consumers [14]. This structure can have very significant faults in urban and rural areas, leading to service discontinuity. In this article, the investigated network consists of a three-phase source, a power transformer, two loads, a busbar, and a D-STATCOM connected at the point of common coupling (PCC), as illustrated in **Figure 1**, in order to provide reactive power compensation and limit fault currents. The network parameters listed in **Table 1** were selected to accurately represent a realistic medium-voltage (MV) distribution network.

Table 1. The network parameters.

Parameters	Values
Source voltage	230 kV
Grid frequency	50 Hz
Power transformer	230/50 kV
Line resistance	0.3 Ω
Line inductance	4 mH
DSTATCOM filter resistance	0.01 Ω
DSTATCOM filter inductance	1 mH
DC-link voltage	800 V
Load 1	1 MW
Load 2	500 kW

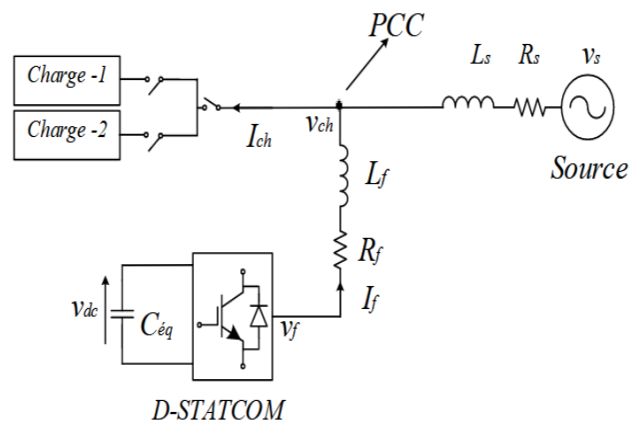


Figure 1. DSTATCOM coupled to the network [15].

3. DSTATCOM Modeling and Control

3.1. DSTATCOM Modeling

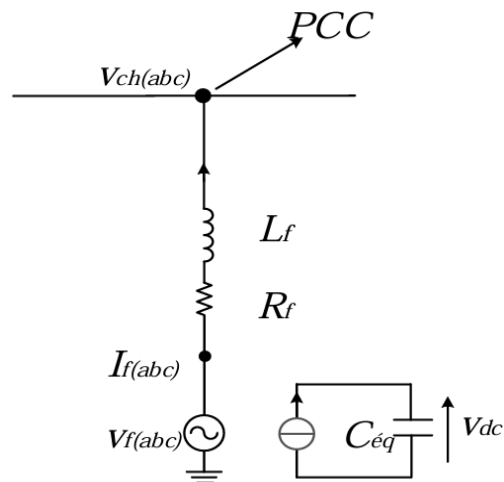


Figure 2. Simplified structure of DSTATCOM coupled to the network.

Figure 2 represents the DSTATCOM coupling to the distribution network for injection or reduction of reactive power. The state model of a DSTATCOM in the (abc) frame is;

$$\begin{aligned}\frac{di_{fDa}}{dt} &= \frac{1}{L_{fD}}(-i_{fDa}R_{fD} + V_{fDa} - V_{cha}) \\ \frac{di_{fDb}}{dt} &= \frac{1}{L_{fD}}(-i_{fDb}R_{fD} + V_{fDb} - V_{chb}) \\ \frac{di_{fDc}}{dt} &= \frac{1}{L_{fD}}(-i_{fDc}R_{fD} + V_{fDc} - V_{chc})\end{aligned}\quad (1)$$

DC side:

$$\frac{dv_{dc}^2}{dt} = \frac{2(V_{cha}i_{fDa} + V_{chb}i_{fDb} + V_{chc}i_{fDc})}{C}\quad (2)$$

According to Clarke transformation in the rotating (d-q) frame, the state model of a DSTATCOM is given in the form:

$$\begin{aligned}\frac{di_{fDd}}{dt} &= \frac{1}{L_{fD}}(i_{fDd}R_{fD} + V_{fDd} - V_{chd} - L_{fD}\omega i_{fDq}) \\ \frac{di_{fDq}}{dt} &= \frac{1}{L_{fD}}(-i_{fDq}R_{fD} + V_{fDq} - V_{chq} + L_{fD}\omega i_{fDd})\end{aligned}\quad (3)$$

DC side:

$$\frac{dv_{dc}^2}{dt} = \frac{2V_{chd}i_{fDd}}{C}\quad (4)$$

3.2. DSTATCOM Control

The D-STATCOM is based on a voltage source inverter (VSI) supplied by a DC voltage source and is connected to the electrical network through an inductive filter. **Figure 3** illustrates the implemented control strategy, which is structured around the following key components:

1) A Pulse Width Modulation (PWM) scheme is employed to ensure a fast system response under short-circuit conditions while limiting switching losses. A switching frequency of 5 kHz is selected in the simulation setup as a compromise between dynamic performance and efficiency. The modulation index is set to 0.9, allowing effective utilization of the DC link voltage while preventing converter saturation during severe fault conditions.

2) A PID controller is integrated with the PWM scheme to achieve a rapid dynamic response during fault occurrence, while effectively limiting the magnitude of short-circuit currents and maintaining DC link voltage stability. The controller gains were tuned to obtain an optimal trade-off between response speed, transient overshoot limitation, and damping of oscillations in the injected current. The exact parameter values used in the simulations are $K_p = 15$, $K_i = 800$, and $K_d = 0.02$.

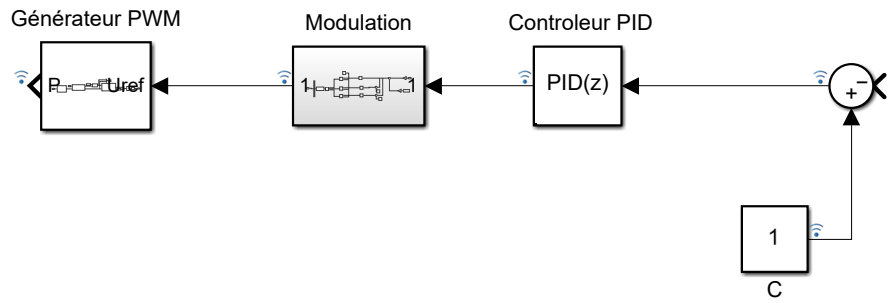


Figure 3. DSTATCOM control.

4. Simulation Results and Analysis

Simulations performed in MATLAB/Simulink show that in the absence of DSTATCOM, single-phase, two-phase, and three-phase faults result in very high short-circuit currents. The integration of DSTATCOM significantly reduces these currents. Figure 4 shows the designed model of the distribution network with fault and DSTATCOM coupling.

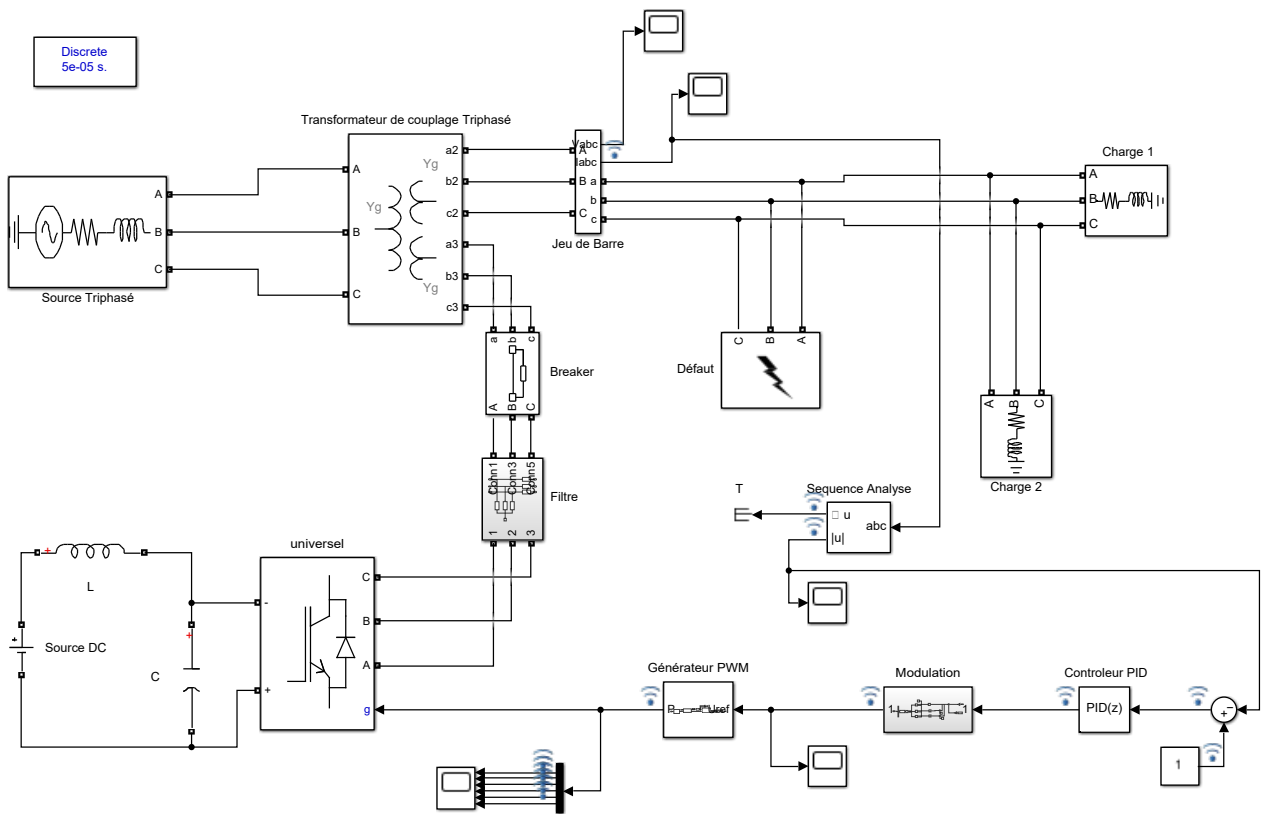


Figure 4. Distribution network model with DSTATCOM.

4.1. Single-Phase Short-Circuit

4.1.1. Behavior without DSTATCOM

Simulation of the single-phase short-circuit increases the current supplied by the power network during the fault interval. During the fault, phase A voltage drops

abruptly to a value close to zero, indicating the presence of the short-circuit. The evolution of phase A current is illustrated by strongly disturbed behavior during the fault, as shown in **Figure 5**.

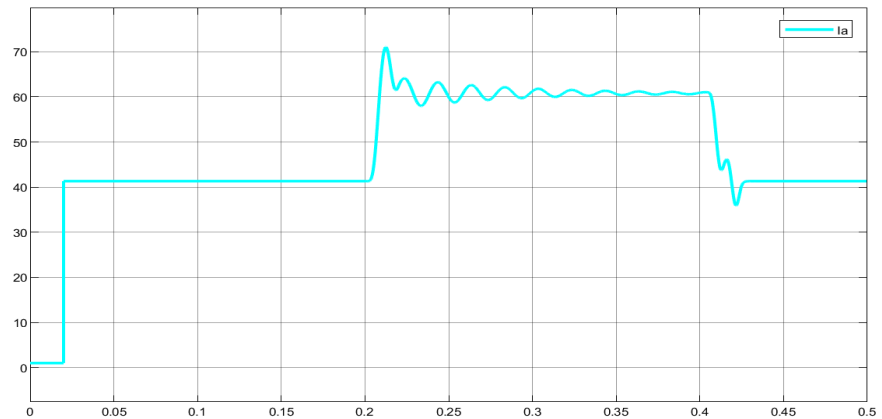


Figure 5. Fault without DSTATCOM.

4.1.2. Behavior with DSTATCOM

Figure 6 presents the configuration integrating the D-STATCOM for fault current reduction under a single-phase short-circuit applied over the time interval 0.2 s to 0.4 s. The simulation results highlight a noticeable, though moderate, reduction in the fault current magnitude. The current in phase A is limited to approximately 22 kA, compared to a peak value of 70 kA in the absence of the D-STATCOM, thereby confirming the effectiveness of the compensator for this type of fault.

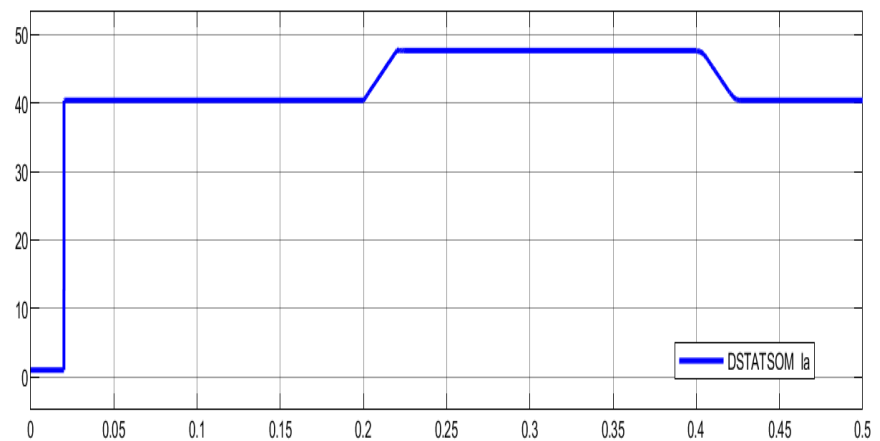


Figure 6. Fault with DSTATCOM.

4.2. Two-Phase Short-Circuit

4.2.1. Behavior without DSTATCOM

During a two-phase short-circuit between phases B and C, the fault current reaches a higher amplitude than that observed in the single-phase fault case, as shown in **Figure 7**. The currents flowing in the two affected phases exhibit opposite polar-

ties, indicating a significant imbalance in the electrical system.

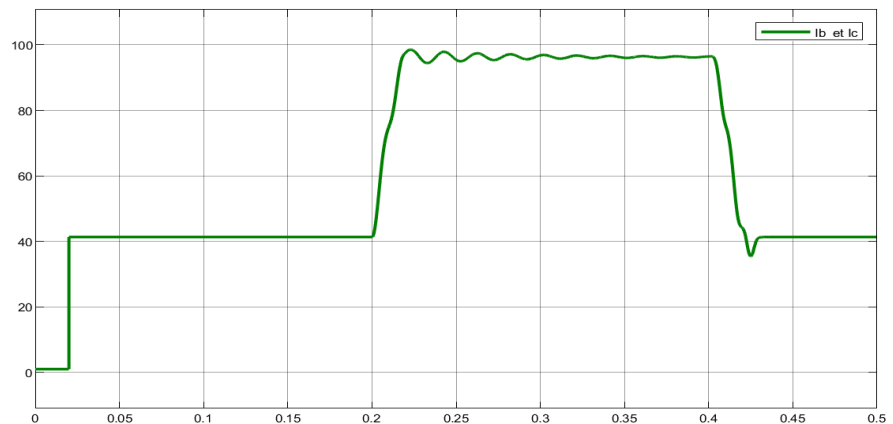


Figure 7. Fault without DSTATCOM.

4.2.2. Behavior with DSTATCOM

In the case of the two-phase short-circuit, simulation results reveal an even more pronounced reduction in the fault current compared to the single-phase fault, as illustrated in **Figure 8**. The currents in phases B and C, which are directly affected by the fault, are significantly limited, with a reduction of approximately 30 kA relative to the peak current recorded without the D-STATCOM. This configuration therefore demonstrates the high effectiveness of the device in limiting two-phase fault currents.

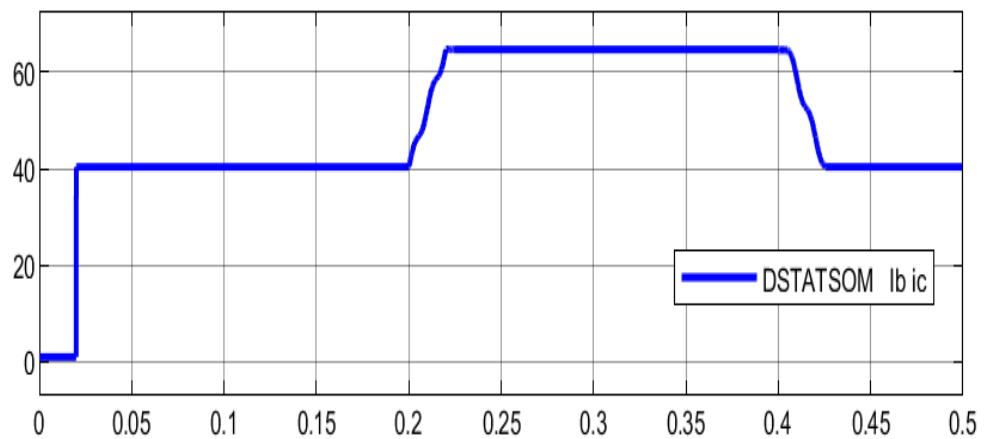


Figure 8. Fault with DSTATCOM.

4.3. Three-Phase Short-Circuit

4.3.1. Behavior without DSTATCOM

A three-phase short-circuit simultaneously affects phases A, B, and C, leading to a very large increase in the fault current, clearly exceeding the levels observed during single-phase and two-phase faults, as shown in **Figure 9**. This type of fault thus represents the most severe operating scenario for the electrical distribution network.

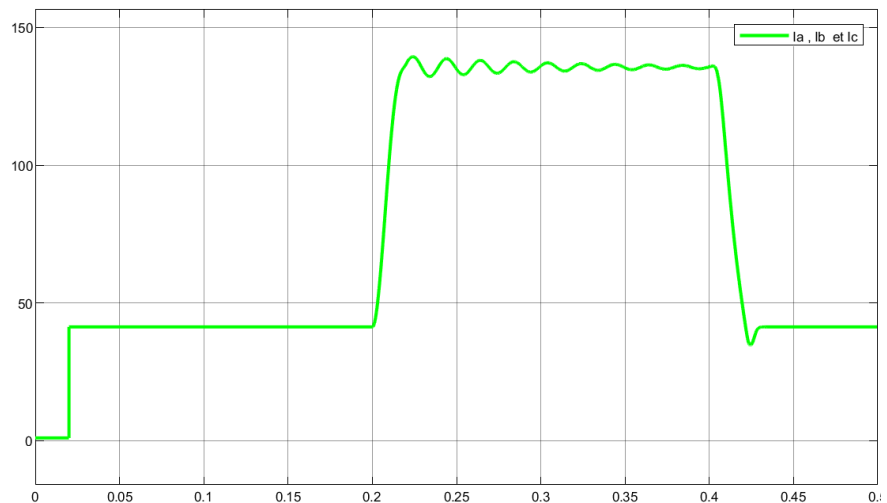


Figure 9. Fault without DSTATCOM.

4.3.2. Behavior with DSTATCOM

For the three-phase short-circuit condition, the simulation results indicate that the DSTATCOM provides the maximum fault current reduction compared to the single-phase and two-phase cases. The fault currents in all three phases are limited to approximately 37 kA, as demonstrated in **Figure 10**, thereby confirming the effectiveness of the device in mitigating the impacts of the most severe faults on the distribution network.

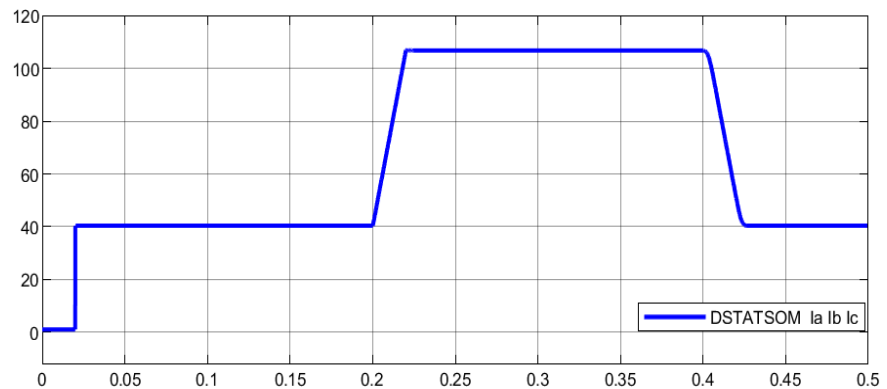


Figure 10. Fault with DSTATCOM.

5. Discussion

Comparative analysis highlights that DSTATCOM effectiveness depends on the fault type and its location in the network. The regulated action of DSTATCOM based on short-circuit current constitutes an important advantage for protection coordination. DSTATCOM proves particularly effective in severe faults, especially three-phase short-circuits.

6. Conclusion

This study has shown that DSTATCOM constitutes an effective technological so-

lution for limiting short-circuit currents in distribution networks. Simulation results confirm its essential role in improving network stability during faults. Although this study does not account for constraints related to protection systems and network parameters such as line resistance and reactance, DSTATCOM appears as an economically viable technological solution, particularly suitable for developing country networks.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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