Adequate compensation of dstatcom-based fgs for mitigating the impact of source disturbances in radial power systems

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Keywords

D-STATCOM, sensitive load, FGS controller, response optimizer, voltage disturbance.

Abstract

Electrical power systems are often exposed to disturbances due to various factors (internal and external). One of these disturbances is source voltage disturbance. The source voltage sags and swells, significantly affecting sensitive loads and the rest of the system's equipment, causing them to work less well or even break down. Because of this, the effects of these disturbances on the power system should be lessened. One of the most effective solutions is to employ modern power electronics technologies such as Distribution Static Synchronous Compensator (D-STATCOM) as one of the custom power devices. Conventional PI controllers are commonly used in D-STATCOM but are not adaptive to large disturbances, which can lead to significant performance degradation. Also, the tuning methods of their parameters are tedious and time consumed. In this work, a fuzzy gain scheduled (FGS) controller integrated with PI parameters was used to provide adaptive performance in a wide range of source voltage disturbances for a radial power system. The optimal parameters were found by the response optimizer tool. Simulation of the system operation was carried out using MATLAB/Simulink software. The simulation results showed adaptive performance and superiority in response speed and overshoot value in the fuzzy control unit compared to the traditional PI units.

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1. Introduction

Previously, consumer equipment was immune to short-term power fluctuations and didn’t cause electrical grid problems. But now, the nature of loads in industrial, commercial, and residential facilities has changed as a result of the widespread use of modern technology that relies on computing and microprocessors, so most electrical appliances and equipment are described as sensitive loads, which require feeding them from a high-quality source, in addition to being continuous. The power quality problem refers to any deviation of voltage, frequency, and current from its standard values, which can be a reason for malfunction or poor performance of customer equipment. Among power quality problems, sag and swell in voltage are the most common problems (sag happens up to 80% of the time) (Shahgholian and Azimi 2016). For customers, the economic impact of these electrical power quality disturbances can reach millions of dollars, while for electric utilities, electrical power quality disturbances lead to dissatisfaction with consumers and decreasing income. So, the electrical power quality importance is significantly increasing for both electric utilities and customers (Van den Broeck, Stuyts, and Driesen 2018).

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The magnitude of supply voltage is a parameter that should be preserved in the overall power system. Any change in the source voltage magnitude results in voltage changes at all system levels. The distribution level is regarded as the most system-level affected by power quality problems due to two reasons: firstly, the increased use of renewable energy sources is interconnected with the distribution system, and these interrupted sources result in several power quality problems that affect the performance of the whole system, and secondly, the end users' power quality problems are coupled with the distribution system. The nature of renewable energy sources or the loads, whether inductive or capacitive, heavy or light, and the nonlinear customer devices that draw non-sinusoidal currents that pollute the supply system, are all these issues regarded as important issues and require creative solutions continuously (Mararakanye and Bekker 2019; Naderi et al. 2018).

Reactive power compensation is one of the most significant power quality problem solutions. It has benefits for improving voltage profile, power factor correction, voltage stability, and increased transfer and operation capacity of lines and devices of the system, in addition to reducing energy losses (Abdelsalam, Ghoneim, and Salem 2022). Conventionally, it has used devices such as capacitor banks, tap changers, and Static Var Compensators for reactive power compensation. however, these devices suffer from many disadvantages, such as slow response, bulky size, resonance, high losses, noise, and require continuous maintenance (Gawande, Khan, and Ramteke 2013). But with the rapid development of the semiconductor industry and control systems in recent decades, fast compensation has enabled using controllable power electronic devices. These compensation devices are the Custom Power Devices (CPD) and Distribution Static Synchronous Compensator (DSTATCOM) is an essential device of this family (Masdi et al. 2004).

DSTATCOM is installed in parallel near sensitive loads to improve power quality. It is broadly used for sag and swell voltage mitigation, power factor correction, harmonic elimination, and voltage or load balancing (Gupta, Fritz, and Kahn 2017). The CPD includes other compensation devices like series type, namely Dynamic Voltage Restorer (DVR) (Danalakshmi, Bugata, and Kohila 2019) and hybrid type, namely Unified Power Quality Compensation (UPQC) (Qasim, Alsammak, and Tahir 2022).

In (Eltamaly et al. 2021) the PI unit is used in DSTATCOM to regulate AC voltage due to its simplicity of installation and ease of implementation. However, during the validation and modification process, the response degraded. Generally, the PI unit suffers from some disadvantages, such as not being adaptive; in other words, its performance is degraded at significant disturbances because its parameters are designed for specific conditions. Also, these parameters are tuned in traditional methods like trial and error, which are tedious and time consumed and do not provide an optimal response permanently (Nguyen, Nguyen, and Le 2020).

In this work, intelligent techniques have been utilized to overcome these disadvantages. An optimization method has been used to find optimal PI parameters for all points of working with the help of the response optimizer tool, and the fuzzy gain schedule was utilized to provide adaptivity in the controller. Two fuzzy units for both (Kp and Ki) controlling were created by Adaptive Neuro Fuzzy Interference System (ANFIS) to override the complication of fuzzy controllers' design.

2. Distribution static synchronous compensator

DSTATCOM mainly consists of a transformer and coupling reactance, a voltage source converter, dc energy storage, a controller, and a harmonics filter as depicted in Figure (1)(Kumar, Kumar, and Akella 2014). The transformer is used to match the output voltage of the converter with the grid voltage, the coupling reactor provides isolation between the grid and converter, the voltage source converter is working to generate three-phase ac voltages from dc voltage, and a filter is used to remove ripples from converter current (Arya et al. 2020).

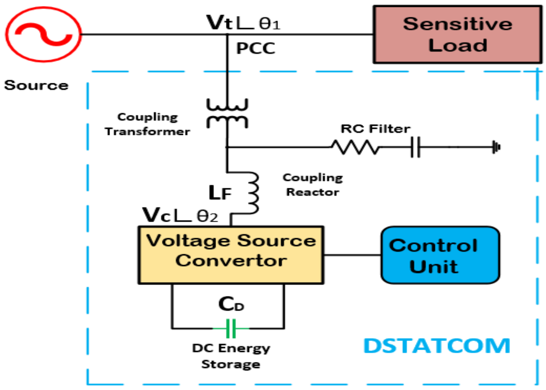


Figure 1. Main parts of DSTATCOM

2.1 Working principle of DSTATCOM

DSTATCOM is connected to the grid at the point of common coupling (PCC) where it is required to address the power quality problem. The compensation of reactive power depends on the voltage difference between the magnitude of grid voltage (V_t) and converter output voltage (V_c), if (V_t) is smaller than (V_c) the reactive compensation will be transferred from DSTATCOM to the grid, but if (V_t) is greater than (V_c) the reactive compensation will be transfer from the grid to DSTATCOM, while there is no reactive compensation transferred if the two voltages are equal (Adnan and Alsammak 2020). Practically, there is a small phase shift between the grid voltage angle (θ_1) and the compensator voltage angle (θ_2) allowing to transfer of small active power from the grid to DSTATCOM to cover the internal losses of the latter, the equations (1), (2), (3) are used to calculate phase shift angle (δ), active and reactive power transferred (Yousif and Mohammed 2021).

$$\delta = \theta_1 - \theta_2 \tag{1}$$

$$P = \frac{V_t V_c}{X} \sin \delta \tag{2}$$

$$Q = \frac{V_t (V_t - V_c \cos\delta)}{X} \tag{3}$$

Where δ is a phase shift angle, θ_1 is a grid voltage angle, θ_2 is a compensator voltage angle, P is an active power, Q is a reactive power, V_t is a grid voltage, V_c is a converter voltage, and X is a coupling reactance.

2.2 Controlling in DSTATCOM

The controller plays a vital role in the functioning of DSTATCOM. Its function is to take samples of the system voltages and currents and compare them with the reference values and resulting in an error value which used to extract the appropriate signals for the pulses generator to trigger switches of the voltage source converter for an adequate compensation of reactive power value to mitigate the power quality problem at this point (Latran, Teke, and Yoldaş 2015). As Synchronous Reference Frame (SRF) or dq theory used in the conventional control of DSTATCOM, it is needed PI units for each AC voltage regulator, DC voltage regulator, and current regulator, as shown in Figure 2 (Bapaiah 2013).

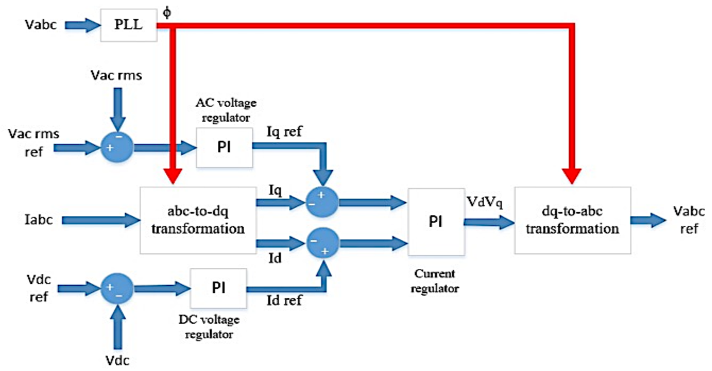
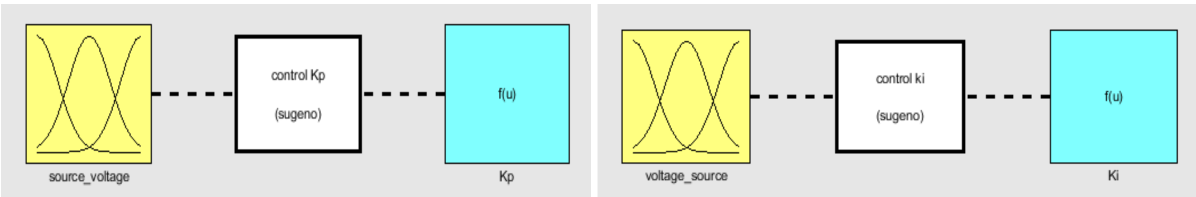


Figure 2. Conventional PI control of DSTATCOM

The response optimizer tool in Matlab was used to get the optimal Kp and Ki parameters at different source voltage values. These (input/output) data sets had downloaded in the ANFIS editor, as shown in Figure. 3, the two fuzzy systems are created to control both Kp and Ki by the intelligent controller, which is a combination of fuzzy and PI units (FGS). This proposed FGS unit is instead with the conventional PI unit in an AC voltage regulator to produce proper reference compensation component and adequate reactive compensation at the different voltage values of the source. Figure. 4 show the proposed control unit in the AC voltage regulator.



(a) (b)

Figure 3. Proposed fuzzy logic system.
(a) Fuzzy logic control of Kp.
(b) Fuzzy logic control of Ki.

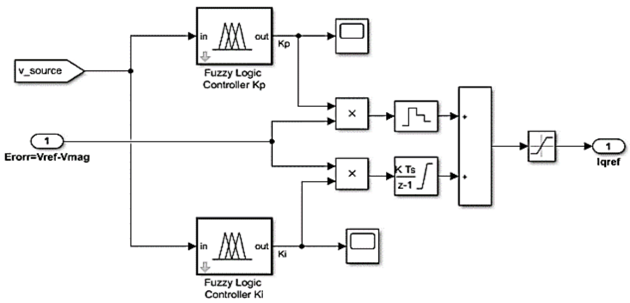


Figure 4. The scheme of proposed control (FGS) unit in the AC voltage regulator of DSTATCOM

3. Simulation result

Simulations were carried out on the radial distribution power system shown in Figure 5. using Simulink/Matlab package. This system consists of a voltage source, three buses, transmission lines between them, and a distribution transformer at bus 3 feeds a sensitive load at its end, in addition to loads at buses 1 and 2. The DSTATCOM is connected close to the sensitive load at bus 3. The simulation is performed with and without DSTATCOM for both the two cases of disturbance in the source voltage shown in the subsections below:

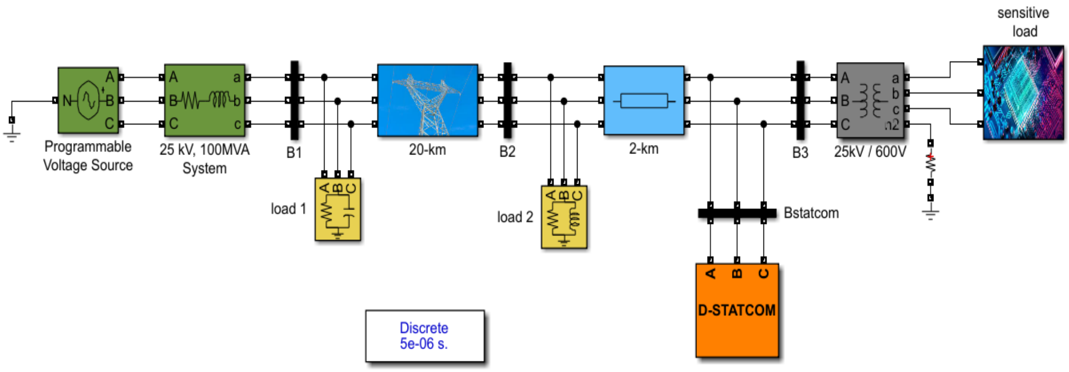
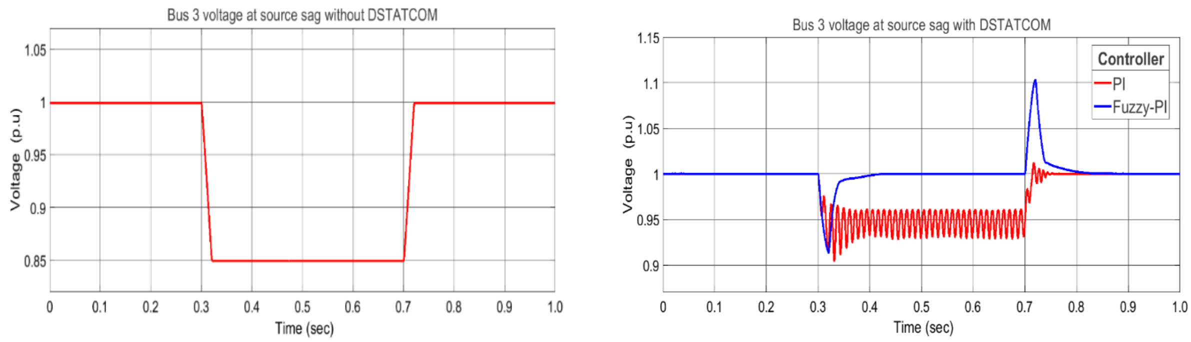


Figure 5. The radial power system simulated in Matlab

3.1. A sag of source voltage

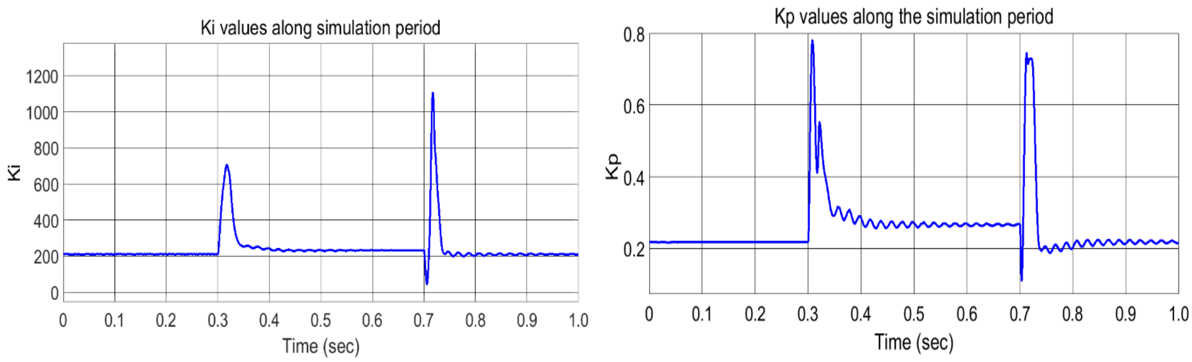
The first disturbance was the source voltage sagging, which was represented by a decrease in the source voltage for the period (0.3 to 0.7 s) by a value of (0.15 p.u). As a result, without using DSTATCOM, the voltage was decreased to (0.85 p.u) at bus 3, as shown in Figure (6a).

DSTATCOM of a PI control unit was connected to the system, and the simulation had a rerun. The voltage at bus 3 is red in Figure (6b). It is clear, through the appearance of continuous voltage fluctuation throughout the disturbance period, that DSTATCOM did not regulate the voltage to the nominal value due to the PI control unit not working correctly, which caused inappropriate compensation and bad performance of DSTATCOM. The simulation had rerun after connecting DSTATCOM with the proposed fuzzy-PI control unit. The apparent improvement in its work and response is noted in mitigating this disturbance and regulating the voltage to the nominal value (1 p.u) within a short time of about 0.08s, as shown in Figure (6b) in blue; the reason behind that is the appropriate compensation through the proper working of the proposed control unit. Figure (7) shows the optimal Kp and Ki parameters of a fuzzy controller provided for the PI control unit continuously when the source voltage changes through the disturbance period.



(a) (b)

Figure 6. Bus 3 voltage at source sag (a) without DSTATCOM (b) with DSTATCOM



(a) (b)

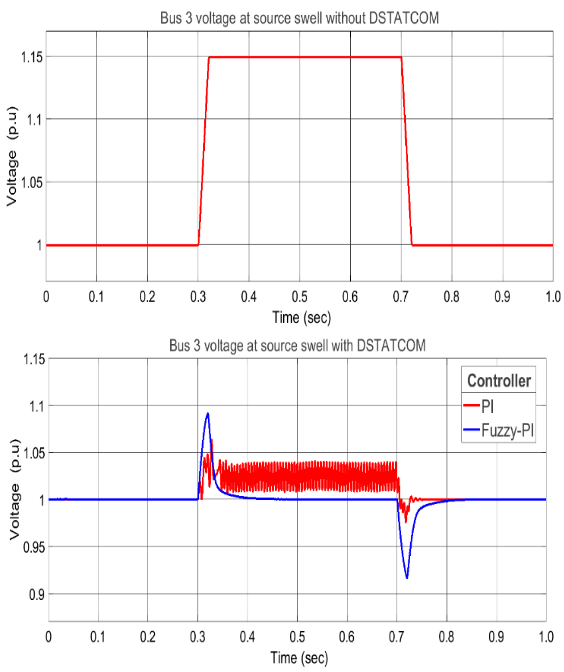
Figure 7. Fuzzy unit output at source swelling simulation for a parameter of (a) Ki, (b) Kp

3.2. A swell of source voltage

It is one of the disturbances that badly affects the performance of sensitive loads. It may lead to them going out of work, which may have internal causes such as increased excitation of the synchronous generator and poor control prosses, or external such as turning on a capacitors bank or turning off a large inductive load (Al juboori, Al-Younus, and Alrawe 2022). This disturbance was done by applying an increasing source voltage by a value of 0.15 p.u for a period 0.3 to 0.7 s. As a result, without using DSTATCOM, the voltage was increased to (1.15 p.u), as shown in Figure (8a).

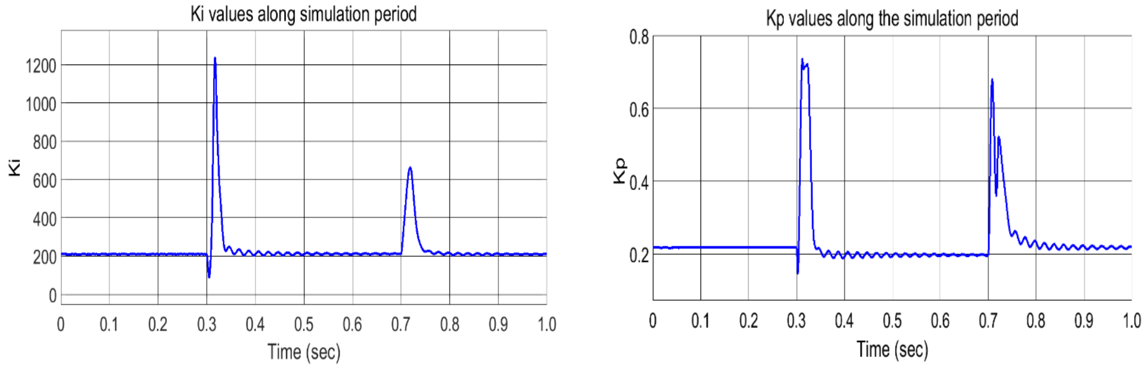
DSTATCOM of a PI control unit was connected to the system, and the simulation had a rerun. The performance of the DSTATCOM was bad, as this disturbance was not mitigated, and the fluctuation of the voltage along the disturbance period appeared as a result of the incompatibility of the original PI parameters with the system conditions during the disturbance, as shown in Figure (8b) in red.

The simulation had rerun after connecting DSTATCOM for this case with the proposed fuzzy-PI control unit. The performance of DSTATCOM was significantly improved, as depicted in Figure (8b) in blue color. This intelligent response will provide optimal control parameters at all voltage source values. These optimal parameters are reflected in the compensator's response and, consequently the compensation process's efficiency. Figure (9) shows the optimal values changing of Kp and Ki parameters through the source voltage disturbance period.



(a) (b)

Figure 8. Bus 3 voltage at the swelling of source (a) without DSTATCOM (b) with DSTATCOM



(a) (b)

Figure 9. Fuzzy unit output at source swelling simulation for a parameter of (a) Ki, (b) Kp

4. Conclusion

Voltage source disturbances badly affect the power quality in electric power systems. Sensitive loads require high power quality to operate correctly with high efficiency. Reactive power compensation is one of the most effective solutions to reduce disturbances in electrical power systems. It must be an appropriate value in the shortest time to ensure effective compensation. DSTATCOM is custom power devices broadly used due to its ability to mitigate various disturbances. The traditional PI controller is commonly used, but it suffers from some problems, such as; a lack of adaptation to significant disturbances or changing system conditions and weaknesses in its tuning methods. Optimization with the help of Artificial Intelligent techniques was used to obtain the optimal parameters of Pi controller, in addition to replacing the traditional controller with an intelligent one composed of integrating the fuzzy controller with PI units. The simulation results showed performance and response advancement of a proposed intelligent control unit and a significant improvement in mitigating disturbances of sagging and swelling source voltage compared to traditional unit that suffers from delayed response and oscillation.

Conflict of interest

There was no conflict of interest between the authors during the creation of this study. No financial support has been received and there are no conditions that provide financial or personal benefit.

Contribution of authors

The authors involved in this study are Ahmed Samir Alhattab, Dr. Ahmed Nasser B. Alsammak, Dr. Hasan Adnan Mohammed; contributed to all aspects of the study. All authors contributed to the idea, design, inspection, resources, data collection, literature review, critical review and analysis and interpretation sections of the study.

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