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Mitigate Voltage Sags under Unbalanced Faults and Islanded Fault Condition Using FD-STATCOM

Divya Achanta [1], K. Mahesh [2]

M. Tech Student Scholar, Department of Electrical & Electronics Engineering, BV RAJU Institute of Technology, Narsapur, Meadk (D), Telangana, India.

Associate Professor, Department of Electrical & Electronics Engineering, BV RAJU Institute of Technology, Narsapur, Meadk (D), Telangana, India.

ABSTRACT: This paper proposes a flexible D-STATCOM (Distribution Static Compensator) and its new controller system, that be able to mitigate both unbalanced faults and fault under islanded condition and operate as a Distribution Generator (DG), when it supplies power to sensitive loads while the main utility source is disconnected (i.e., it is under islanded operating condition). Thus D-STATCOM operates same as flexible DG (FDG) and consequently, it is called Flexible D-STATCOM (FD-STATCOM). In this paper, the 12-pulse FD-STATCOM configuration with IGBT is designed and the graphic based models of the FD-STATCOM are developed using the MATLAB/ Simulink program. The performance of FD-STATCOM is to mitigate voltage sag problems and to improve distribution system performanceunder unbalance faults such as L-L & D-L-G faults and supplies power to sensitive loads under islanding condition. The reliability and robustness of the control schemes in the system response to the voltage disturbances caused by faults under islanded operating condition are obviously proved in the simulation results.

KEYWORDS: FD-STATCOM, voltage sags, islanding condition, test system

1. INTRODUCTION

A voltage sag or voltage dip is a short duration reduction in RMS voltage which can be caused by a short circuit, overload or starting of electric motors. Voltage sag happens when the RMS voltage decreases between 10 and 90 percent of nominal voltage for one-half cycle to one minute.

The modern power distribution system has an ever growing demand. Many loads at various distribution sides like domestic utilities, adjustable speed drives have become intolerant to voltage fluctuations. One of the most severe problems faced in distribution network is voltage drip in distribution feeders, which is caused by real and reactive power flow. Voltage can be improved and power losses can be reduced by installing custom power devices at suitable location. These devices are aimed at enhancing the reliability and quality of power flow in low voltage distribution networks.Custom power devices have the ability to perform solutions for current interruption and voltage regulation functions within a distribution system.

There is a high demand for utility Distribution generator (DG) installations due to their advantage of upgrading the distribution system. Generally, these sources are connected to grid through inverters and their main function is to deliver active power into the grid. The DGs are designed to supply active power or both active and reactive power. Flexible DG systems would indeed be possible to implement integrated functions like harmonic mitigation, unbalance mitigation, zero sequence component suppression schemes, and etc. The new trends in power electronic converters make the implementation of such multiple functions feasible. A DG is islanded when it supplies power to some loads while the main utility source is disconnected. Islanding detection of DGs is considered as one of the most important aspects while interconnecting DGs to the distribution system. With the increasing penetration of distribution systems on DGs, the new interface control strategy is being proposed [1].

Solar Photo Voltaic (PV) is a particularly attractive form of renewable generation, given that it can be relatively easily installed togenerate electricity that is consumed by local loads, with any excess power being fed back into the utility network. It is a proven technology and the costs have dropped dramatically to the point that the resulting cost of electricity is comparable to tariffs charged by distributors. The technological developments and cost reductions have been driven by the large scale deployment of solar PV in several countries.

The integration of Renewable Energy (RE) in the electricity network however presents various challenges ranging from power quality (PQ), power flow control, voltage and frequency stability, new requirements for simulation tools, and the revision of Grid Standards. Solar PV plants are connected to the grid via inverters utilizing pulse width modulation (PWM). The switching nature can result in degradation of power quality in the interconnection network, potentially resulting in grid guideline violations. As such, control systems need to be designed to take into account the network parameters, grid regulations, and the state of the PV plant.

In distribution systems the important issue is to control the reactive power compensation. Losses in a distribution system increases due to increase in a reactive current and thus it reduces systems power factor and also shrink the capability of active power and cause large amplitude variations in the load side voltage [2-3]. Various methods have been used to mitigate voltage sags. The conventional methods use capacitor banks, new parallel feeders, and uninterruptable power supplies (UPS). However, the power quality problems are not completely solved due to uncontrollable reactive power and high costs of new feeders and UPS.

This paper proposes a flexible D-STATCOM system designed to operate in two different modes. Initially it can mitigate voltage sags caused by unbalanced faults. Secondly, it can mitigate voltage sags caused by three phase open circuit fault by opening the three phases of a circuit-breaker and disconnecting the main power source that is in an islanding condition.

The D-STATCOM has emerged as a promising device to provide solutions not only for voltage sag mitigation but also become a host for other power quality solutions like voltage stabilization, flicker suppression, power factor correction, and harmonic control[4]. D-STATCOM is a shunt device that generates a balanced three-phase voltage or current with ability to control the magnitude and phase angle [5].Unlike the Unified power flow controller (UPFC) which consists of two parts, series and shunt, to manage the flow of active power from one part to the other, FDG consist of one part only, because it has a supply of the active power from DG system. A control method based on RMS voltage measurement had been presented in [6] and [7] where they have been presented as a PWM based control scheme that requires RMS voltage measurements and no reactive power measurements are required. In addition, Clark and park transformations are not required in this method. However they have been investigated voltage sag/swell mitigation due to load variation while no balanced and unbalanced faults have been investigated. In [8] and [9], a lookup table is used to detect the proportional gain of PI controller, which is based only on trial and error. While in this paper, fuzzy based controller is used formitigating the load voltage sags caused by unbalanced faults. Then the robustness and reliability of the proposed method is more than the mentioned methods. Here the D-STATCOM is modified for mitigating voltage distortions and the effects of system faults on the sensitive loads are investigated and the control of voltage sags are analyzed and simulated.

II. PROPOSED FD-STATCOM

The D-STATCOM configuration consists of a typical 12-pulse inverter arrangement, a DC energy storage device and a coupling transformer connected in shunt with AC system. The configurations that are more sophisticated use multilevel configurations. The voltage source converter (VSC) converts the DC voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the AC system of network through the reactance of the coupling transformer

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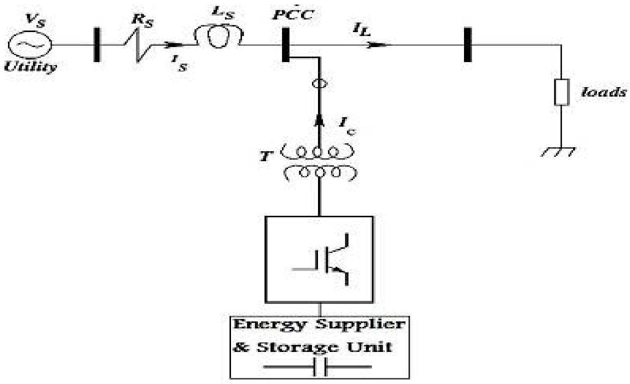

[10].

Figure 1: Schematic representation of FD-STATCOM

Fig.1 shows the schematic representation of the FD-STATCOM. The basic electronic block of the FD-STATCOM is the voltage source inverter that converts an input DC voltage into a three-phase output voltage at fundamental frequency. These voltages are in phase and coupled with the AC system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the FD-STATCOM output voltages allows effective control of active and reactive power exchanges between the FD-STATCOM and the AC system.

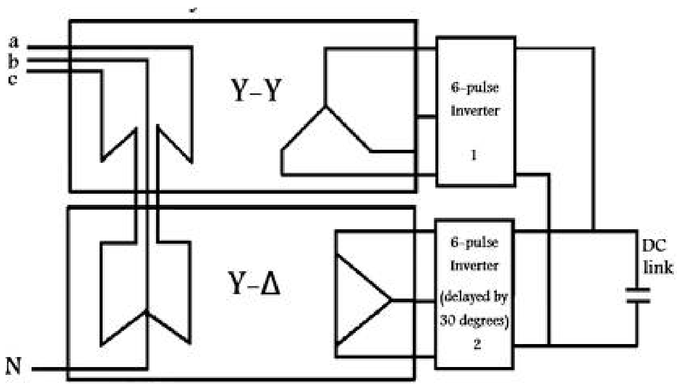

Figure1:12-pulse inverter arrangement

Fig. 2 shows a typical 12-pulse inverter arrangement utilizing two transformers with their primaries connected in series. The first transformer is in Y-Y(star-star) connection and the second transformer is in Y-Δ (star-delta) connection. Each inverter operates as a 6-pulse inverter, with the Y-Δ inverter being delayed by 30 degrees with respect to the Y-Y inverter. The Insulated-gate bipolar transistors (IGBTs) of the proposed 12-pulse FD-STATCOM are connected anti parallel with diodes for commutation purposes and charging of the DC capacitor [11]. This is to give a 30 degrees phase shift between the pulses and to reduce harmonics generated from the FD-STATCOM. The FD-STATCOM is connected in shunt to the system.

III. CONTROL STRATEGY

The block diagram of the control scheme designed for the FD-STATCOM is shown in fig. 3. It is based on measurements of the Vrms (RMS Voltage) voltage at the load point.

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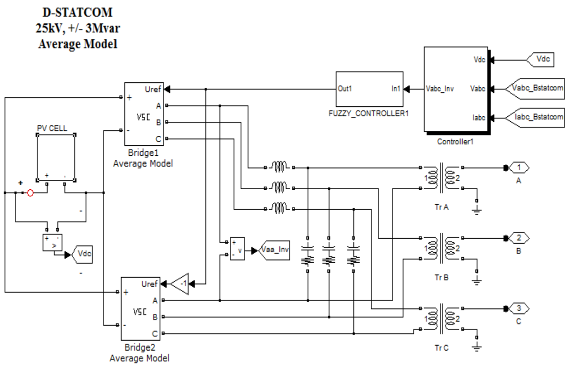

Figure2: Control Scheme designed for the FD-STATCOM

The fuzzy controller is used in this proposed model in order to obtain and compare the error signals.Unlike other controllers fuzzy control has no trial and error way of problem solving. It automatically sets the gain values for the inverters and thus compensates both error and change in error values. As the fuzzy controller has membership functions we can convert them as required. Fuzzy controller has set of rules and logics and works based on fuzzy tables.

IV. PROPOSED CONTROL MEDTHOD

A Distribution Static Synchronous Compensator (D-STATCOM) is used to regulate voltage on a 25-kV distribution network. Two feeders (21 km and 2 km) transmit power to loads connected at buses B2 and B3. A shunt capacitor is used for power factor correction at bus B2. The 600-V variable load connected to bus B3 through a 25kV/600V transformer represents a plant absorbing continuously changing currents, depending on the transformer energizing, thus producing voltage sags. The variable load current magnitude is modulated at a frequency of 5 Hz so that its apparent power varies approximately between 1 MVA and 5.2 MVA, while keeping a 0.9 lagging power factor. This load variation will allow you to observe the ability of the D-STATCOM to mitigate voltage sag.

The D-STATCOM regulates bus B3 voltage by absorbing or generating reactive power. This reactive power transfer is done through the leakage reactance of the coupling transformer by generating a secondary voltage in phase with the primary voltage (network side). This voltage is provided by a PV cell which is connected to the controller. We can use a battery or a capacitor connection to the PV for storage purpose. When the secondary voltage is lower than the bus voltage, the D-STATCOM acts like an inductance absorbing reactive power. When the secondary voltage is higher than the bus voltage, the D-STATCOM acts like a capacitor generating reactive power.

A D-STATCOM consists of a 25kV/1.25kV coupling transformer which ensures coupling between the inverter and the network. Here the PWM inverter is replaced on the AC side with three equivalent voltage sources averaged over one cycle of the switching frequency (1.68 kHz). Harmonics generated by the inverter are therefore not visible with this average model. On the DC side, the inverter is modeled by a current source charging the DC capacitor. The DC current (Idc) is computed so that the instantaneous power at the AC inputs of the inverter remains equal the instantaneous power at the DC output. LC damped filters connected at the inverter output. Resistances connected in series with capacitors provide a quality factor of 40 at 60 Hz. 10000-microfarad capacitoris used which acts as a DC voltage source for the inverter. Voltage regulator controls voltage at bus B3. Anti-aliasing filtersare used for voltage and current acquisition.In the fuzzy controller a unit delay is attached. This parameter can minimize unwanted output behavior. Here the sample time for unit delay block is set to -1. The setting time -1 means sample time is inherited.The programmed FIS (fuzzy interface system) file is imported to the workspace, thus on simulation it can rectify all the error and change in error values. The electrical circuit is discretized using a sample time Ts=40 microseconds.

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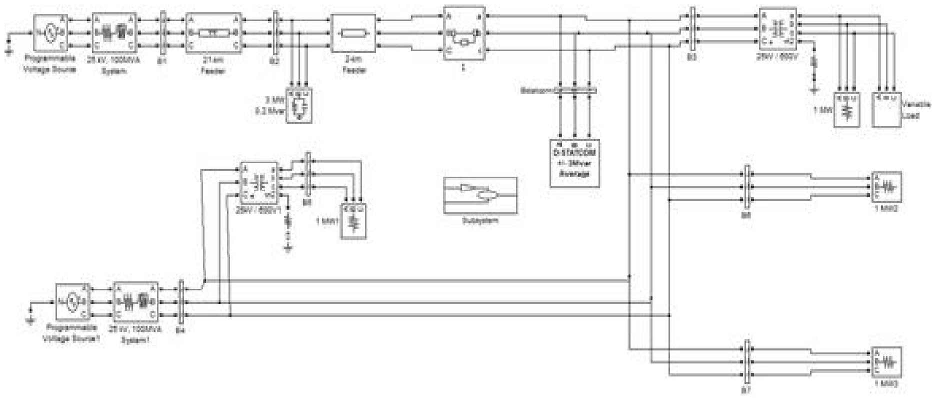

Figure 3: Distribution system with FD-STATCOM integrated with PV and Fuzzy controller

During this test, the variable load will be kept constant and you will observe the dynamic response of a D-STATCOM to step changes in source voltage. Check that the modulation of the Variable Load is not in service (Modulation Timing [Ton Toff] = [0.15 1]*100 > Simulation Stop time). The Programmable Voltage Source block is used to modulate the internal voltage of the 25-kV equivalent. The voltage is first programmed at 1.077 pu in order to keep the D-STATCOM initially floating (B3 voltage=1 pu and reference voltage Vref=1 pu). Three steps are programmed at 0.2 s, 0.3 s, and 0.4 s to successively increase the source voltage by 6%, decrease it by 6% and bring it back to its initial value (1.077 pu).

Start the simulation. Observe on Scope the phase a voltage waveforms of the D-STATCOM (RMS voltages). After a transient lasting approximately 0.15 sec., the steady state is reached. Initially, the source voltage is such that the D-STATCOM is inactive. It does not absorb nor provide reactive power to the network. At t = 0.2 s, the source voltage is increased by 6%. The D-STATCOM compensates for this voltage increase by absorbing reactive power from the network (Q=+2.7 Mvar on trace 2 of Scope2). At t = 0.3 s, the source voltage is decreased by 6% from the value corresponding to Q = 0. The D-STATCOM must generate reactive power to maintain a 1 pu voltage (Q changes from +2.7 MVAR to -2.8 MVAR).

V. SIMULATION RESULTS

The test system comprises a 25kv transmission system. A balanced load is connected to the 600v secondary side of the transformer. Breaker.1 is used to control the operation period of the FD-STATCOM. A 12 pulse FD-STATCOM is connected to the secondary winding by closing breaker.1 at 0.2 s, for maintaining the load RMS voltage at 1pu. A capacitor on the DC side of the FD-STATCOM provides storage capabilities. The simulations are carried out for both cases where the FD-STATCOM is connected to or disconnected from the system. The simulations of the FD-STATCOM in fault conditions are done under unbalanced fault and also islanded condition. In islanded condition three conductors are opened by breaker.2. The duration of the islanding condition are considered for about 0.1 s. in LL and DLG faults the faulted phases are A and B and the duration of faults are considered for about 0.3 s for these unbalanced faults.

During this test, voltage of the Programmable Voltage Source will be kept constant and you will enable modulation of the Variable Load so that you can observe how the D-STATCOM can mitigate voltage sag. In the Programmable Voltage Source block menu, change the "Time Variation of" parameter to "None". In the Variable Load block menu, set the Modulation Timing parameter to [Ton Toff] = [0.15 1] (remove the 100 multiplication factor). Finally, in the D-STATCOM Controller, change the "Mode of operation" parameter to "Q regulation" and make sure that the reactive power reference value Qref (2nd line of parameters) is set to zero. In this mode, the D-STATCOM is floating and performs no voltage correction. Run the simulation and observe on Scope variations of voltages at buses B1 and B3 (trace 2). Without D-STATCOM, B3 voltage varies between 0.96 pu and 1.04 pu (+/- 4% variation). Now, in the D-STATCOM Controller, change the "Mode of operation" parameter back to "Voltage regulation" and restart simulation. Observe on Scope that voltage fluctuation at bus B3 is now reduced to +/- 0.7 %. The D-STATCOM compensates

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voltage by injecting a reactive current modulated at 5 Hz (trace 3 of Scope3) and varying between 0.6 pu capacitive when voltage is low and 0.6 pu inductive when voltage is high.

As we mainly focused on the voltage sags in the distribution system, only RMS voltages are shown in the simulation results. Based on the purpose of the test we can go for load voltage outputs, Total Harmonic Distortion (THD), Active and Reactive values etc.

Fig. 5 shows the RMS voltages respectively, for the case when the system operates without FD-STATCOM and under LL fault.

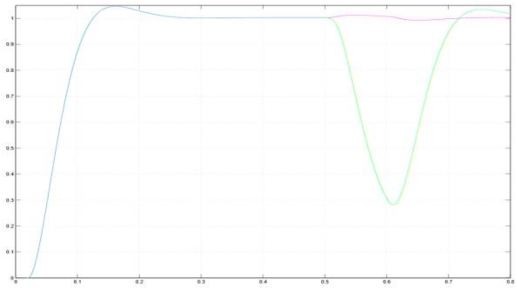

Figure 5: RMS voltages without FD-STATCOM under LL fault

Fig. 6 shows the FD-STATCOM connection to the distribution system. The voltage drop of the sensitive load point is mitigated using the proposed control method. The RMS voltage value is obtained very effectively with this new method of voltage regulation.

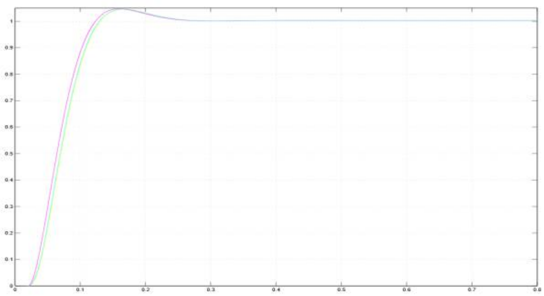

Figure 6: RMS voltages with FD-STATCOM under LL fault

Fig. 7 shows the RMS voltages at the load point, for the case when the system is operated without FD-STATCOM under unbalanced DLG fault.

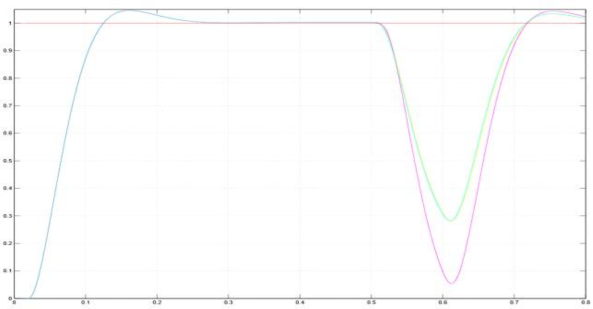

Figure 74: RMS voltages without FD-STATCOM under DLG fault

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Fig. 8 shows the compensated RMS voltages under DLG fault using proposed method. It observed that the proposed method has correctly mitigated the voltage sag.

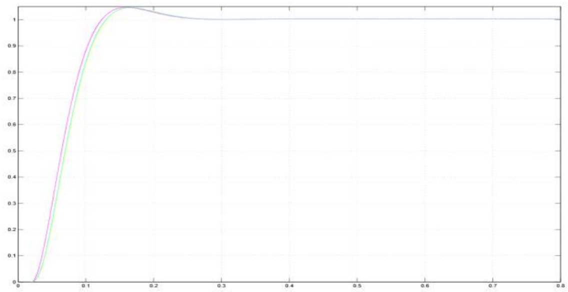

Figure 8: RMS voltages with FD-STATCOM under DLG fault

Fig. 9shows the RMS voltages respectively, for the case when the system operates without FD-STATCOM under islanded condition.

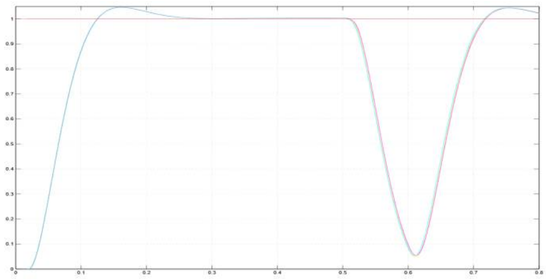

Figure 9: RMS voltages without FD-STATCOM under islanded condition

Fig. 10shows the compensated RMS voltages under islanded condition using proposed method. It is observed that the proposed method had correctly mitigated the voltage sag.

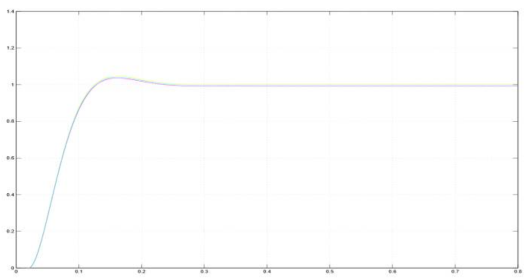

Figure 10: RMS voltages with FD-STATCOM under islanded condition

VI. CONCLUSION

In this paper, a Fuzzy logic is used in the control system to obtain more efficiency and better results for fault mitigation (voltage sags).PV is usedin the testsimulation design we can replace PV with wind, fuel cells and other renewable sources. We can implement this simulation and can make further extension with the help of artificial neural networks and genetic algorithms to obtain much more efficiency, reliability and robustness to the distribution system.

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