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A Combination of Appropriate Placement and size of Multiple FACTS Controllers to reduce Voltage Sag and Swell

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ABSTRACT- Today's power system is going through a power quality crisis as a result of rising power demand and an increase in industrial facilities. The forms must be pure sinusoidal and harmonic-free, and the power source must always be reachable within voltage and frequency restrictions. This study uses numerous FACTS controllers in a radial distribution system to handle power quality concerns. Placement of FACTs controllers in the distribution system under various load conditions presents the biggest challenge. The system is run while deploying single and multiple FACTS controllers at the critical buses in order to avoid conflicts. This paper presents on the installation of a DSTATCOM, Integrated Dynamic Voltage Restorer-Ultra Capacitor (IDVR-UC), and UPQC to reduce power quality issues for conventional IEEE-33 bus distribution systems.

Keywords: DSTATCOM; Harmonic Distortion; IDVR-UC, UPQC; Voltage Sag; Voltage Swell.

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1. INTRODUCTION

A steady supply or continuous load is necessary for equipment in an emergency. These loads are currently quite sensitive, and they are increasing as a result of these restrictions, which directly affect transmission and distribution stations. [1-2] For sensitive loads, power quality is essential. If the power quality is not beyond acceptable levels, issues such as voltage sags and swells, malfunctions, and financial and maintenance losses may result [3].

Many electronic devices are used in industrial automation, smart grid systems, image processing, and medical applications with a unique set of dynamic, non-linear demands. There are problems with power quality as a result, and the voltage profile will alter. Some of the problems with power quality are voltage sag (a drop in voltage), very short interruptions (a break in the supply), voltage spikes (changes in voltage), voltage swell, and harmonic distortions [4-6].

Power consumption satisfaction is a big problem since it raises the cost of power plant maintenance. Power electronic devices are utilized to reduce system maintenance costs. As the power electronics family progresses, there are several technical options for addressing the aforementioned power system issues [7-8]. FACTS devices are excellent for maintaining a constant voltage at the point of common connection (PCC). The usage of FACTS devices can improve the reliability and power quality of the power system [9]. There are several methods to compensate for anything, but the most efficient and cost-effective one is to employ FACTS devices [10].

Poor electricity quality is addressed with FACTS technology. Each FACTS device has a different working mode for power regulation, including voltage source control (VSC), dynamic voltage restore (DVR), D-STATCOM, and IPFC [11]. Each device is used to reduce voltage fluctuations and enhance the system's operation. The DVR topology is a more effective and efficient control mechanism with a lower cost [12].

To safeguard the load from problems caused by voltage sags and swells, a DVR is used on the distribution feeder. The DVR is wired in parallel with the load. The DVR injects energy into the distribution system to maintain voltage stability, and the DVR is connected to the system via the transformer [13].A FACTS device, the DVR adjusts for load disturbances such as voltage harmonics and sags. The DVR normally injects a small number of voltages in series with the transmission lines and a small number of volts [14-20]. The voltages are then supplied into the system to keep the system stable. When a disturbance occurs, however, the DVR gives or takes active or reactive

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power from the dc-link rather than taking or providing it in the steady state. [21-25].

Modeling and simulation of customized power conditioners are necessary since power electronics-based equipment is utilized to enhance power quality in distribution networks [18]. The following are some of the extended merits of the UPQC [26-28]. It is also the most complete tool for improving power quality for nonlinear loads that need a precise sinusoidal input supply [29-32].

The rest of the paper is like in Section 2 of the study presents the problem formulation. Section 3 presents DSTATCOM, IDVR-UC, and UPQC modeling. How to carry out the research is described in Section 4. The simulation results are shown and discussed in section 5. The conclusions are formed in Section 6.

2. SYSTEM MODEL

Power quality is the preservation of a sinusoidal waveform of bus voltages at rated voltage and frequency. Depending on the cause of the issue, such as converters, magnetic circuit nonlinearity, signal wave structure zones can be established (radio frequency interference). Power quality is the cause, and electrical equipment's capacity to function in such an environment is the outcome [22–25].

2.1 Maximizing Voltage Sag

When the voltage falls by 10% or more below average or advised values, such as when a 120-volt outlet decreases to 90 volts, voltage dips (sometimes referred to as "sags") occur. Both brief power line short circuits and the activation of large motors can cause those [26].

2.2 Minimizing Voltage Swell

On the other hand, voltage swells are the exact opposite of dips and denote voltage surges of at least 10% above typical or tolerable levels. When a heavy load is turned off, the voltage on the power line quickly surges, causing swells [27].

2.3 Minimizing THD

The total harmonic distortion (THD or iTHD) is a signal distortion measurement that is defined as the ratio of all harmonic component powers to the fundamental frequency power [28].

$$THD = \sqrt{\sum_{h=2}^{hmax} h_2} \Big/ M_1 \quad (1)$$

3. FACTS CONTROLLERS

3.1 DSTATCOM

This is like a STATCOM, except that it's used at the Distribution level. It's connected to the distribution systems in close proximity to the load [10-12]. When a VSC is connected to a dc capacitor, a programmable ac voltage source is created, which is the primary premise of a D-STATCOM put in a power system (energy storage device). The modified of DSTATCOM model is given in *figure 1*.

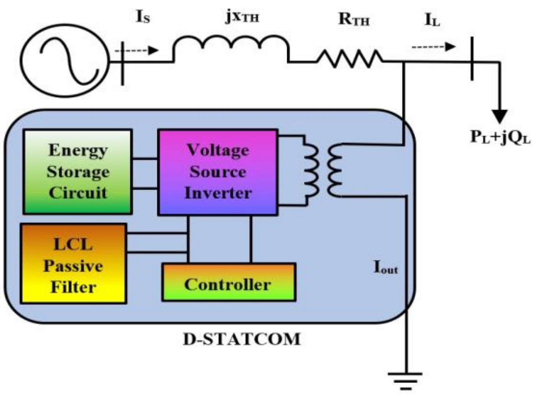

Figure 1: Schematic Diagram of D-STATCOM

The schematic diagram of D-STATCOM is shown in *figure 1*.

$$I_{out} = I_L - I_S = I_L - \frac{V_{th} - V_L}{Z_{th}} \quad (2)$$

$$I_{out} < \gamma = I_L < (\theta) - \frac{V_{th}}{Z_{th}} < (\delta - \beta) + \frac{V_L}{Z_{th}} < (-\beta) \quad (3)$$

The voltage control, greater system stability, better usage of machinery linked to the systems, and reduction of system losses are the key reasons for reactive power compensation.

3.2 Integrated Dynamic Voltage Restorer-Ultra Capacitor (IDVR-UC)

An insulated-gate bipolar transistor (IGBT) module, its gate-driver, an LC filter, and an isolation transformer comprise the inverter system. The dc-link voltage Vdc is set at 260 V for best converter performance, while the line-line voltage Vab is set to 208 V.

$$m = \frac{2\sqrt{2}}{\sqrt{3}V_{dc} * n} V_{ab}(rms) \quad (4)$$

where n is the isolation transformer's turns ratio. When n is replaced with 2.5 in *equation (4)*, the needed modulation index is 0.52. As a result, the output of the dc-dc converter should be set at 260 V to offer correct voltage compensation. The integrated UCAPDVR system with active power capacity is intended to adjust for voltage sags (0.1-0.9 p.u.) and voltage swells (1.1-1.2 p.u.) lasting between 3 seconds and 1 minute.

3.3 Unified Power Quality Controller (UPQC)

The use of UPQC may be used to rectify voltage and current imbalances, cancel current harmonics, remove voltage harmonics, enhance voltage control, correct voltage sag or swell, and minimize voltage disturbance [3].

One of the voltage source inverters is connected in parallel while the other is connected in series to the AC system using injection transformers. For the UPQC to function properly, the DC capacitor voltage must be at least 150 percent greater than the maximum line-line supply voltage.

4. STUDY PROCEDURE

The research was carried out on a 12.6-kV distribution network in an electrical distribution system (EDS). There are 33 buses,

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32 lines (overhead lines and underground cables), and total active power load 3715 kW and total active power 2326 kVAr.

4.1 Step by Step Procedure

Step-1: Initially, the base voltages are obtained from the system.
Step-2: The total power flow and total system losses are obtained by load flow study.
Step-3: The sag in the voltage is observed with the system load.
Step-4: FACTS device is connected in the system as per the location identified with Sag.
Step-5: Similar to Sag, Swell in the voltage is also obtained.
Step-6: One FACTS device at a time is connected in the system to observe voltage sag and swell.
Step-7: The complete analysis is carried as per the test cases given below.

4.2 Test Cases

The following cases are considered to analyze voltage sag and voltage swell.
Case-I: Without FACTS Device in the System
Case-II: With DSTATCOM in the system
Case-III: With IDVR-UC in the system
Case-IV: With UPQC in the system
Case-V: With DSTATCOM & IDVR-UC & UPQC in the system

5. SIMULATION RESULTS

Two key power quality issues were investigated in this study; voltage sag and voltage swell in an electrical distribution system. The simulation results are obtained using MATLAB/ SIMULINK for 10-seconds simulation duration. The data obtained are utilized as a baseline for comparing results from different FACTS devices.

Case 1

The total active and reactive power is 3.715MW+ j2.3MVA and the total real power losses are 202.67kW with voltage values < 0.9 p.u and the same system is examined with the power quality analysis without any FACTS devices. The simulation diagram of the system is presented in *figure 2*. The voltage sag and voltage swell at bus no.15 are given in *figure 3* and *figure 4*. The manual triggered at 0.01 sec to observe at each load bus.

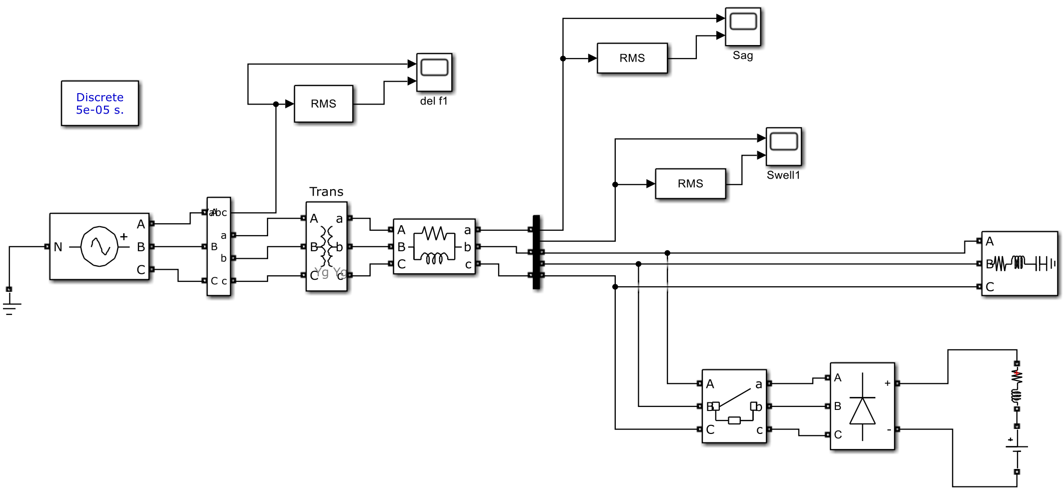

Figure 2: System without FACTS

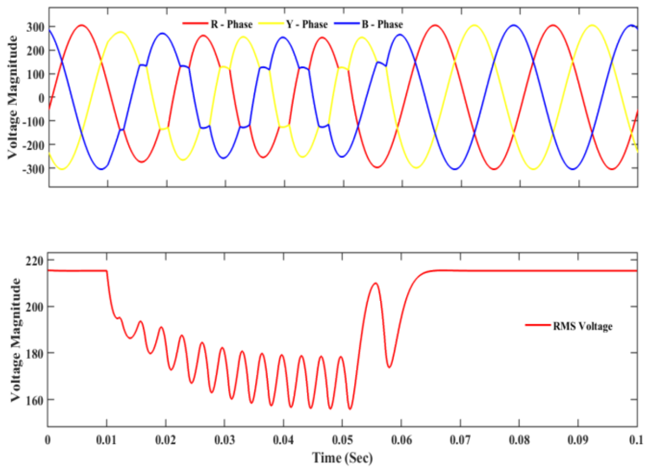

Figure 3: Voltage Sag at Bus no. 15

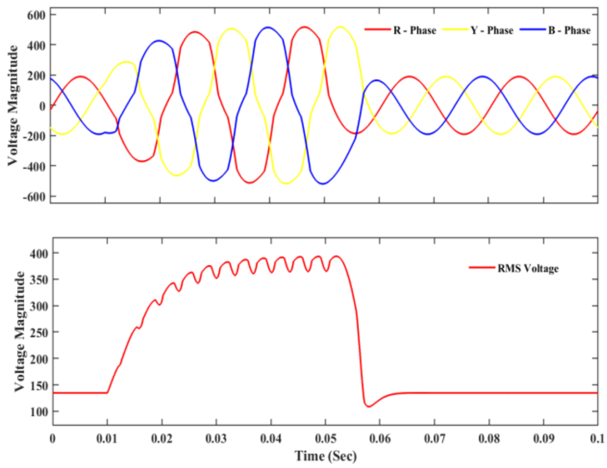

Figure 4: Voltage Swell at Bus no. 15

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Case II

The power quality analysis with DSTATCOM is connected and examined at bus-15, bus-24, and bus-30 with the same load data. The size of DSTATCOM is 3MVAR, calculated for load. The simulation diagram with DSTATCOM is presented in *figure 5*. The voltage sag and voltage swell at bus no.15, are given in *figure 6* & *figure 7*.

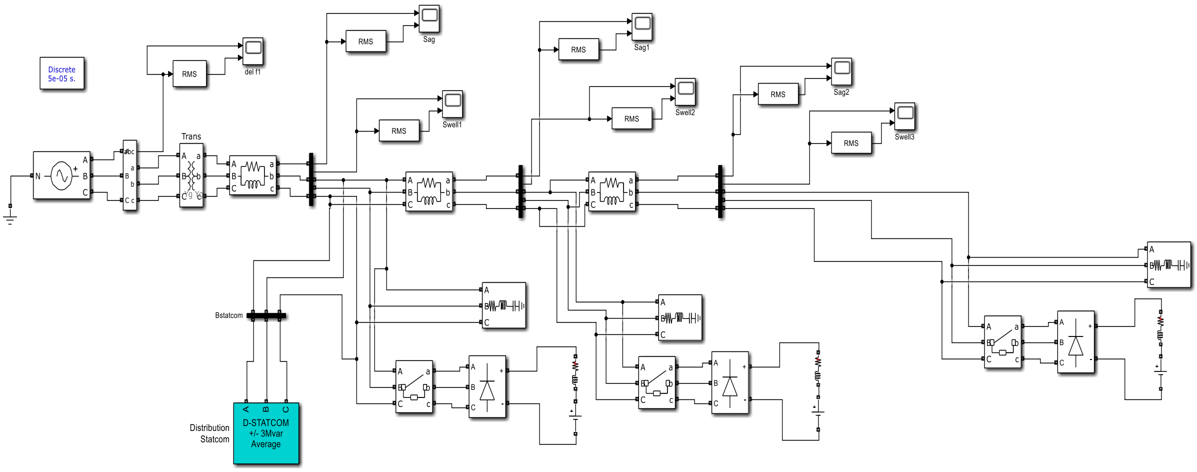

Figure 5: DSTATCOM in the System

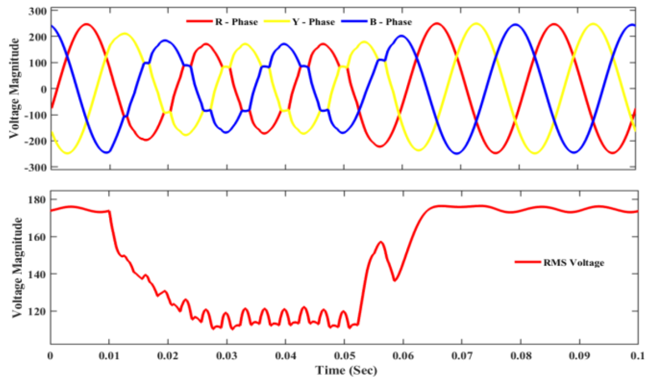

Figure 6: Voltage Sag with DSTATCOM at Bus no. 15

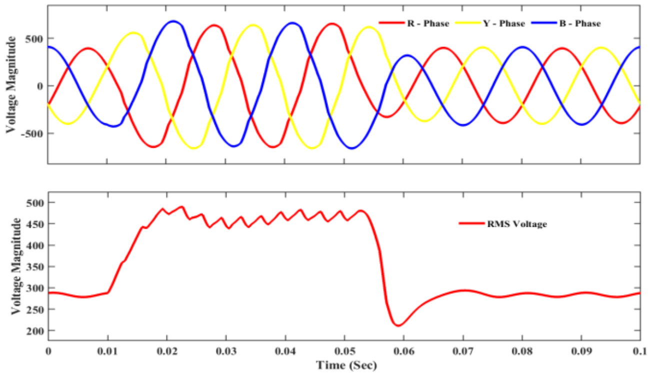

Figure 7: Voltage Swell with D-STATCOM at Bus no. 15

Case III

The power quality analysis with IDVR-UC is connected at bus-15, bus-24 and bus-30 in the system. The size of IDVR-UC is 3 MVAR. The simulation diagram with IDVR-UC is presented in *figure 8*. The voltage sag and voltage swell at bus no.15 are given in *figure 9* to *figure 10*. The fault is created at 0.01 sec to observe the voltage sag and voltage swell at each load bus.

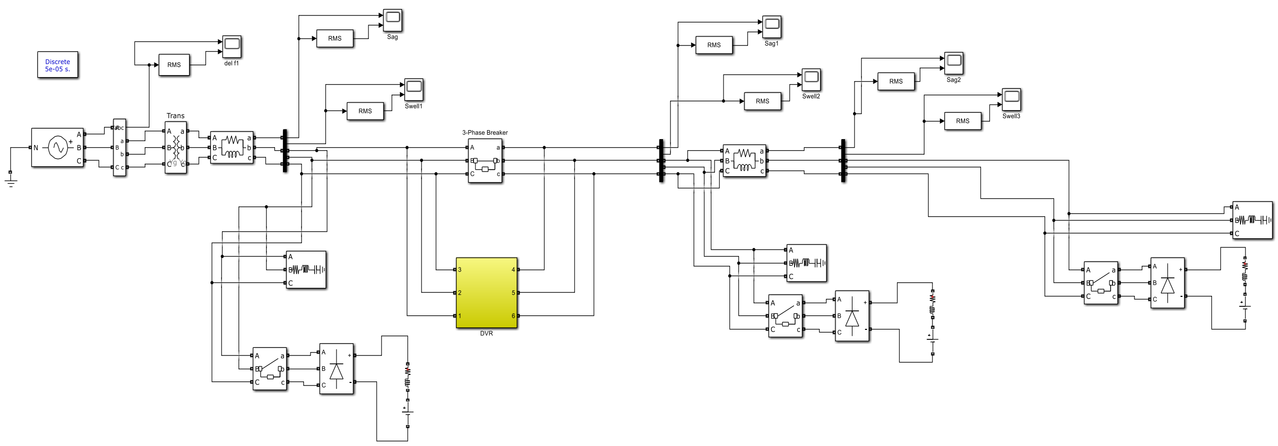

Figure 8: IDVR-UC in the System

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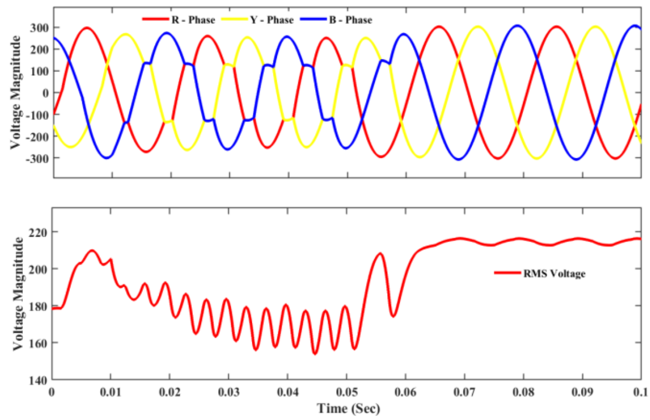

Figure 9: Voltage Sag with IDVR-UC at Bus no. 15

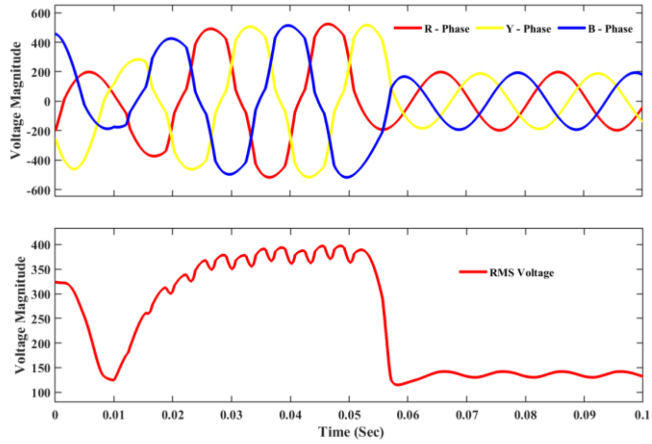

Figure 10: Voltage Swell with IDVR-UC at Bus no. 15

Case IV

The power quality analysis with UPQC is connected at bus-15. The size of UPQC is 3MVAR. The simulation diagram with UPQC is presented in *figure 11*. The voltage sag and voltage swells at bus no.15 is given in *figure 12* and *figure 13*. The fault is created at 0.01 sec to observe the voltage sag and voltage swell at each load bus.

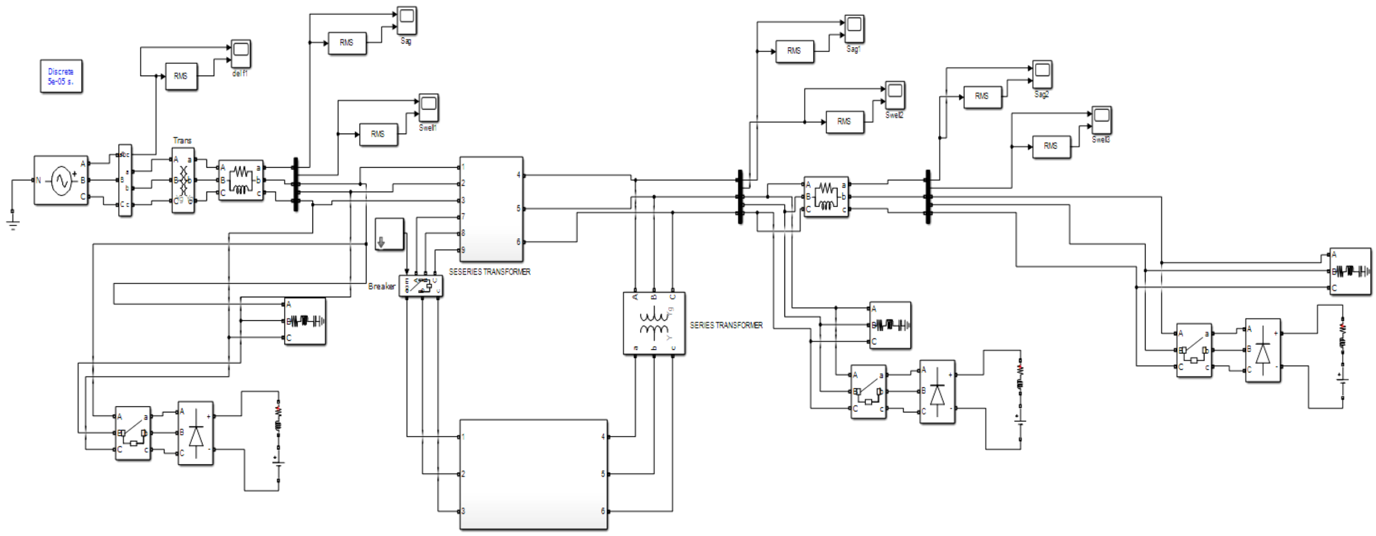

Figure 11: UPQC in the System

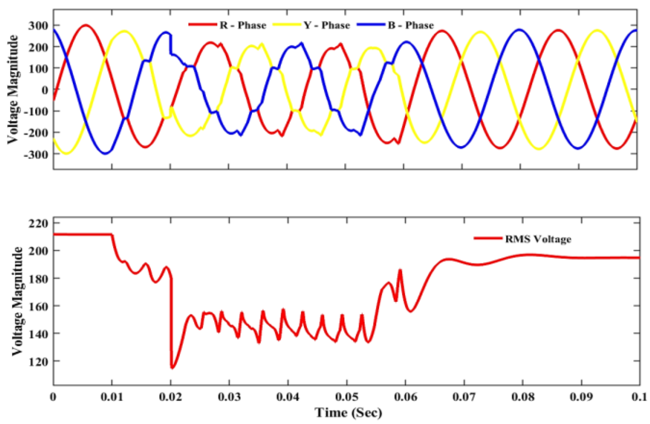

Figure 12: Voltage Sag with UPQC at Bus no. 15

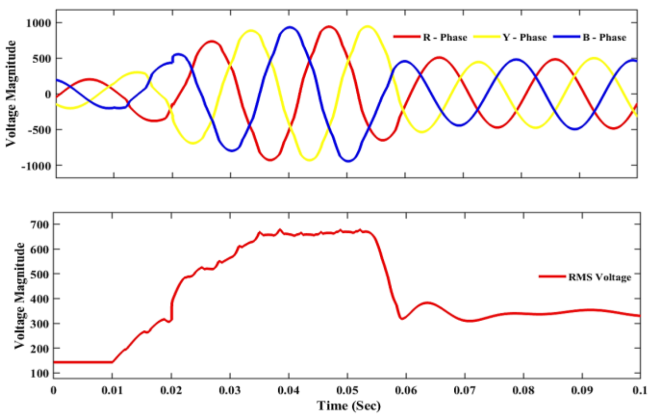

Figure 13: Voltage Swell with UPQC at Bus no. 15

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Case V

The power quality analysis with UPQC & IDVR-UC & DSTATCOM is connected at bus-15 and bus-24 in the system. The size of UPQC & IDVR-UC & DSTATCOM is 5 MVAR. The simulation diagram with UPQC & IDVR-UC & DSTATCOM is presented in *figure 14*. The voltage sag and voltage swell at bus no.15 are given in *figure 15*, and *figure 16*. The fault is created at 0.01 sec to observe the voltage sag and voltage swell at each load bus.

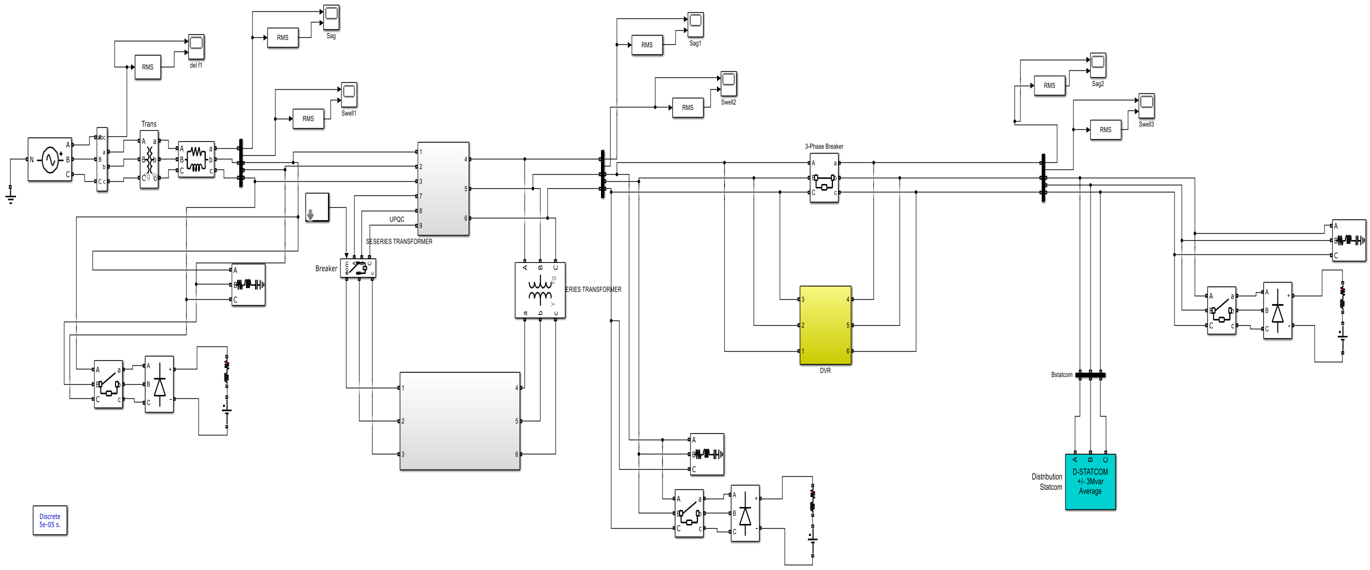

Figure 15: UPQC & IDVR-UC & DSTATCOM in the System

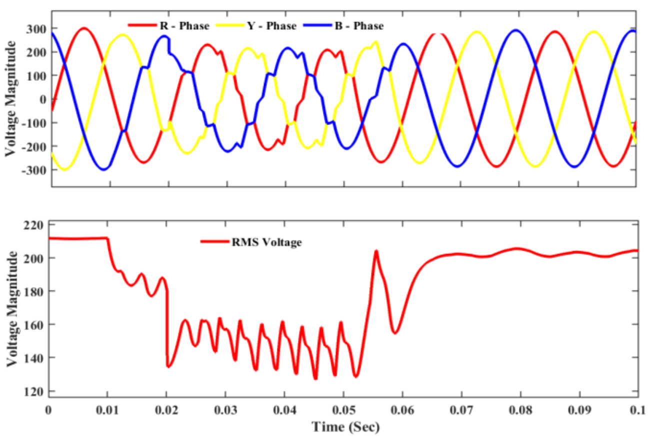

Figure15: Voltage Sag with UPQC & IDVR-UC & DSTATCOM at Bus no. 15

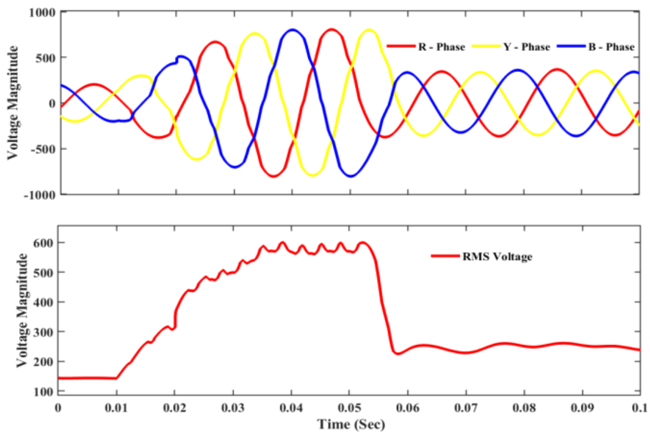

Figure 16: Voltage Swell with UPQC & IDVR-UC & DSTATCOM at Bus no. 15

The Comparison of Voltage sag, swells and total harmonic distortion with and without FACTS devices is given in *table- 1*, *table-2* and *table-3* respectively. The THD is high without FACTS devices and is very low compared to the three devices. If two devices are connected to the system, there is the possibility of getting lower THD for the combination of UPQC & DSTATCOM. However, when all three devices are coupled, the total output THD required is quite minimal.

Table 1: Voltage Sag (per unit) comparison for all situations in the system

Bus No.	C-I	C-II	C-III	C-IV	C-V
4	0.65	0.80	0.81	0.85	0.95
7	0.70	0.82	0.85	0.86	0.98
8	0.64	0.79	0.80	0.79	1.01
14	0.78	0.86	0.89	0.80	0.99
15	0.76	0.88	0.90	0.85	0.97
24	0.80	0.89	0.91	0.92	0.99
25	0.79	0.90	0.90	0.94	0.98
30	0.77	0.89	0.91	0.90	0.97
32	0.64	0.79	0.91	0.92	0.96
33	0.78	0.90	0.91	0.89	0.99

Table-2 Comparison of Voltage Swell (per unit) for all cases in the System

Bus No.	C-I	C-II	C-III	C-IV	C-V
4	1.98	1.05	1.05	1.02	1.00
7	2.53	1.94	1.60	1.21	1.01
8	2.96	1.35	1.28	1.11	1.02
14	2.82	1.51	1.60	1.09	1.03
15	2.37	1.30	1.28	1.05	1.02
24	3.54	1.50	1.46	1.12	1.03
25	2.94	1.09	1.08	1.05	1.01
30	2.68	1.21	1.11	1.08	1.02
32	2.57	1.22	1.08	1.09	1.02
33	2.91	1.08	1.06	1.04	1.01

Table 3: Comparison of THD % for all cases in the System

Parameter	C-I	C-II	C-III	C-IV	C-V
Current	7.70	6.94	7.51	12.05	12.32
	60.24	29.70	39.42	39.64	39.56
	70.23	22.81	40.33	14.36	43.30
Voltage	58.27	15.72	7.12	21.76	21.76
	39.52	8.17	18.58	13.65	17.73
	60.12	14.18	15.81	19.53	39.09

6. DISCUSSION

Based on the results obtained after incorporating various FACTS devices in the system, the discussion about corresponding results is as follows:

In Case-I- without FACTS Device in the System: Voltage Sag is about 160 V and Voltage Swell is 400 V RMS values. In Case-II-with DSTATCOM in the system: Voltage Sag is about 120 V and Voltage Swell is 450 V RMS values. In Case-III-with IDVR-UC in the system: Voltage Sag is about 150 V and Voltage Swell is 450 V RMS values. In Case-IV- with UPQC in the system: Voltage Sag is about 120 V and Voltage Swell is 650 V RMS values. In Case-V- with DSTATCOM & IDVR-UC & UPQC in the system: Voltage Sag is about 130 V and Voltage Swell is 600 V RMS values. Even though all three FACTS devices were connected to the system, the THD was just as good as it was with any other combination of FACTS devices, including the single connection.

7. CONCLUSION

FACTS devices could be added to the radial distribution system to improve its ability to restore voltage. By combining the several FACTS controllers, such as DSTATCOM, IDVR-UC, and UPQC, the system performance is evaluated. These controllers can correct voltage sags and swells on their own rather than relying on the grid to make up for grid faults. The straightforward control approach entails injecting voltages that are in phase with the system voltage. A higher-level integrated controller delivers inputs to the inverter and dc-dc converter controllers depending on system parameters so that they can carry out their control activities. Because of its inherent stability, average current mode control is used to modify the DC-DC converter's output voltage. Even though all three FACTS devices were connected to the system, the THD was just as good as it was with any other combination of FACTS devices, including the single connection.

Conflicts of Interest

Authors declare that no conflicts of interest.

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