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Sustainable Agriculture with Intelligent Power Quality Control in Solar Energy Applications

Prerna Tundwal[1], PhD Scholar at College of Technology and Engineering, Udaipur, India, sainiprerna.97@gmail.com

Hitesh Kumawat[2], PhD Scholar at College of Technology and Engineering, Udaipur, India, hiteshkumawat64@gmail.com

Vikramaditya Dave[3], Associate Professor at College of Technology and Engineering, Udaipur, India, vdaditya1000@gmail.com

Abstract: As the world's population continues to increase the importance of farming practices becomes more and more crucial. The growing use of energy systems, in agriculture has the potential to completely transform the industry by offering renewable power. Nevertheless it is essential to guarantee an efficient power supply to ensure that agricultural operations run smoothly. This paper delves into the connection, between agriculture and the utilization of energy specifically focusing on intelligent control methods for maintaining high power quality. With energy sources, solar power becoming more prevalent in our society addressing power quality challenges in agriculture has become increasingly significant. In this paper we delve into the idea of agriculture by incorporating power quality control into solar energy applications. We address the difficulties that solar systems, in settings encounter in terms of power quality and suggest smart control methods to minimize voltage fluctuations, harmonics and other related problems. The study presented in this paper explores how intelligent control strategies can be designed and implemented to improve power quality, in energy systems used for purposes. By enhancing power quality these systems not ensure efficient farming operations but also contribute to a greener and more sustainable future.

Keywords: Agriculture, applications, intelligent control, power quality, solar energy, voltage fluctuation, harmonics.

I. INTRODUCTION

Recent years have seen a considerable increase in interest in the relationship between agriculture and renewable energy as globally searches for sustainable ways to meet the rising food demand and reduce the carbon footprint caused by traditional farming methods. A key source of power in agriculture, solar energy is now recognised as a clean and plentiful resource that offers a promising route to environment friendly and sustainable farming methods[1]. However, there are challenges that must be solved when integrating solar energy systems into agricultural settings, especially dealing with power quality problems, that could negatively affect the efficiency of crucial farming processes[2].

However, there are a number of challenges involved in integrating solar energy systems into agricultural operations, with power quality being one of the most significant challenges. Highly sensitive agricultural operations can be affected by discontinuous solar power generation caused on by weather conditions, fluctuating voltages, harmonics, and other electrical abnormalities[3]. The sustainability and economic prosperity of agricultural efforts are influenced by the consequences of low power quality, which range from decreased crop yields to damaged livestock[4].

The integration of solar energy applications with a DSTATCOM (Distribution Static Compensator) system is the proposed initiative of this study, which aims to improve sustainable agriculture. The three main objectives of this system are voltage regulation, harmonics reductions, and real-time power quality control[5]. The key objectives are to reduce interruptions in power that could harm farm equipment, facilitate a seamless integration of solar-generated electricity into the agricultural grid, and improve the efficiency and reliability of solar power[6].

The study will also evaluate this integrated approach's benefits for the environment and its economic viability. In order to confirm the system's efficacy in resolving power quality concerns and enhancing farms' overall energy efficiency, real-world trials and data analysis will be carried out[7].

The objective of this effort is to establish a more reliable and efficient energy infrastructure for sustainable agriculture that will support agricultural productivity and environmental preservation by fusing solar energy with DSTATCOM technology[8].

II. DESCRIPTION OF PROPOSED WORK

The proposed work involves the development of a Photovoltaic (PV) based Distribution Static Compensator (DSTATCOM) model specifically designed for agricultural

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applications. The three phase feeder is suitable for medium voltage distribution in rural and agricultural areas since it operates at 11 kV and 50 Hz. The voltage is decreased from 11 kV to 415 V via a step-down transformer with a Yg/Yg construction, which makes it easier to distribute to the end customers[9]. The 150 km long transmission line has significant resistance (R1 = 0.0127 Ω/km, R_0 = 0.3864 Ω/km), inductance (L_1 = 0.9337 mH/km, L_0 = 4.1264 mH/km), and capacitance (C_1 = 12.74 nF/km, and C_0 = 7.751 nF/km)values. Problems with voltage drop, line losses, and power quality are brought on by these characteristics. The load, which is represented by resistance (R=0.3 Ω) and inductance (L=0.486 H), symbolises the agricultural customers using the system's power. These long distance transmission line introduce voltage fluctuation and power quality issues. For mitigation propose a DSTATCOM inverter is introduce The DSTATCOM employs IGBT-based technology, featuring 3 arms and a 6-pulse bridge configuration. It uses a Pulse Width Modulation (PWM) generator with a sampling time of 50 µs and follows a 3-arm, 6-pulse topology to control and inject compensating currents into the system [10].

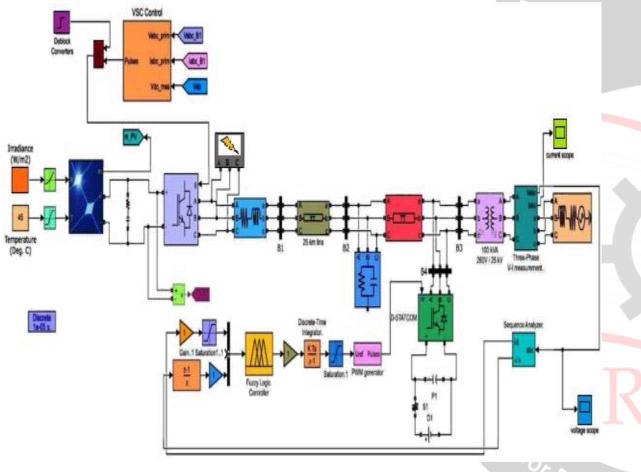

Fig.1: Block diagram of solar photovoltaic system with D-STATCOM to control the power quality

III. PERFORMANCE EVALUATION OF DSTATCOM

We proposed a solar photovoltaic system coupled with distributed static compensator (D-STATCOM) to improve the power quality in agriculture application. Solar panels in the PV system use sunlight to generate DC electricity. This DC power is connected to an inverter, which transforms it into AC power for distribution. The DSTATCOM is constructed simultaneously with the PV system. A voltage source inverter (VSI) or other power electronic converter that can produce compensating currents are frequently found in the DSTATCOM[11]. The converter operates in this case is to control the voltage while covering up power quality problem driven on by the PV system. Voltage and current sensors constantly measure the electrical parameters of the system and provide the control system feedback. This data is analysed by the control system, which is composed of microcontrollers or digital signal processors, that calculates the compensating currents required to maintain stable voltage levels as well as fix any voltage errors driven on by variations in solar energy generation. Real-time injecting of the compensating currents into the distribution network prevents voltage sags, swells, and other problems with power quality[12].

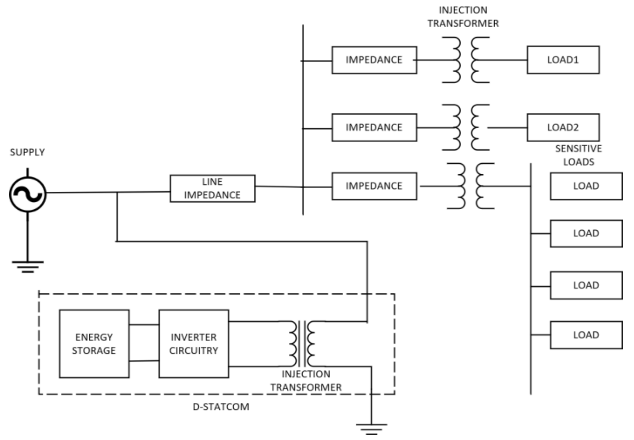

Fig. 2: Location of D-STATCOM in Transmission Line

IV. DESIGN AND CONTROL

A number of crucial parts and control techniques are involved in designing a PV-based Distribution Static Compensator (DSTATCOM) for agricultural applications in order to handle voltage drop, line losses, and power quality problems in an 11 kV, 50 Hz, three-phase distribution system with a 150 km transmission line. For the selection of PV panel for agriculture application some factor consider such as efficiency, reliability and cost[13]. To keep this in mind poly crystalline module type and REIL Solar Make is considered. Since this system is for agriculture and rural area, that panel is robust and weather resistant panel. In solar panel inverter are used that will convert the direct current (DC) into alternative current (AC), for that conversion DELTA inverter make is used that work s with the 415V grid and the D-STATCOM. MPPT algorithms is also used to make sure the PV panels run as efficiently as possible[14].

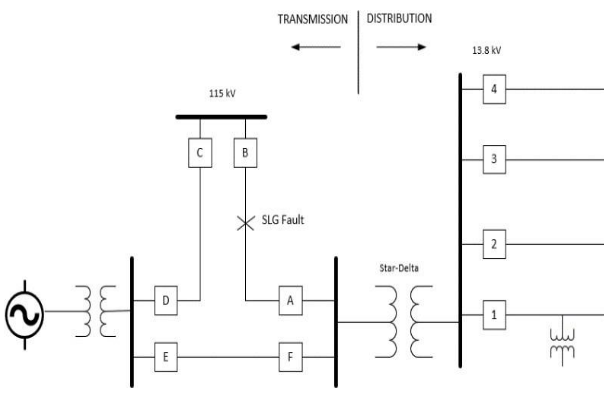

Fig. 3: Faults Location on Utility Power System

This is crucial when working with long transmission lines and fluctuations in voltage. PV panel is control by developing a control system that maintain the PV inverter's

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output voltage and constant it at 415V to assist the DSTATCOM's compensation efforts. Reactive power can be injected to the system by controlling the PV inverter, which will balance line losses and voltage swings. To mitigate problems with power quality, this regulation is crucial. For the PV inverter to function in parallel with the grid and DSTATCOM, make sure it is synchronised with the grid's voltage and frequency[15]. Enable the PV inverter to communicate with the DSTATCOM and other system components by putting in place communication protocols. Managing voltage problems effectively requires coordination between the PV panel system and DSTATCOM. To regularly evaluate the PV panel system's performance, use sensors and monitoring devices. To evaluate and improve the control system, collect information on energy production, voltage, and power quality. To maintain the PV panel system's safe and dependable functioning, provide techniques to identify and address defects such as overvoltage or system faults[16].

Table 1: Electrical Panel Specifications

S.No.	Electrical Properties Under a Standard Temperature	Values
1.	Power Tolerance	0~+8
2.	Panel Efficiency	16%
3.	Current at Maximum Power Point	7.04 A
4.	Voltage at Maximum Power Point	30.03 V
5.	Short Circuit Current	8.02 A
6.	Open Circuit Voltage	36.02 V
7.	Type	Poly Crystalline
8.	PV Module Make	REIL Solar Make
9.	Inverter Make	DELTA

Install an energy management system to maximise the usage of solar power while taking load requirements and power quality limitations into account. When adding power to the grid, in particular, make sure the PV panel system conforms with all applicable local grid norms and laws. Have a plan in place for handling crises or system breakdowns, including backup power sources and isolation techniques[17].

V. RESULT AND DISSCUSSION

A fault is caused at point A for voltage sag 3-Φ Faults of different resistance are formed because the length of the sag depends on the fault resistance. The line voltage, line current, line voltage magnitude, and line voltage's total harmonic distortion (THD) are all included . The load parameters of the system are determined by R=0.33 Ω and L =0.52 H. The 21 kV energy device's D-STATCOM is investigated as follows:

Response during Rf = 0.50 Ω , tr = 0.2s – 0.3s

When D-STATCOM is not connected to the system, a 3-Φ fault is made with a transition time of 0.2s to 0.3s for the resistance of 0.50 Ω, resulting in a 35.9% voltage sag. When D-STATCOM is attached, the voltage sag becomes 5.2% better. The load voltage's THD spectrum improves from 46.29% to 1.54%.

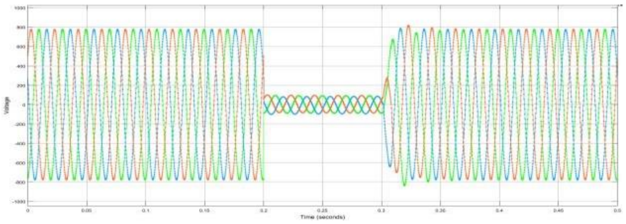

Fig.4: 3- Φ line voltage without D-STATCOM mitigation

As shown in fig.4, A three-phase fault is created, and the fault resistance (R_f) determines how long the sag will last. When the fault resistance is 0.50 Ω, the sag period varies between 0.2 to 0.3 s. The voltage sag is 35.9% prior to the D-STATCOM being attached to the system. This large sag may be harmful to processes and equipment that are sensitive.

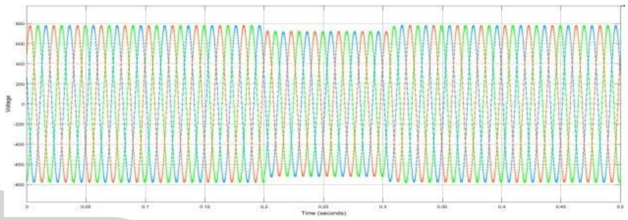

Fig.5: 3- Φ line voltage with D-STATCOM mitigation

As shown in fig.5, After connecting the D-STATCOM the voltage sag improve up to 5.2%. This show that D-STATCOM successfully compensate the voltage drop which is caused by the fault.

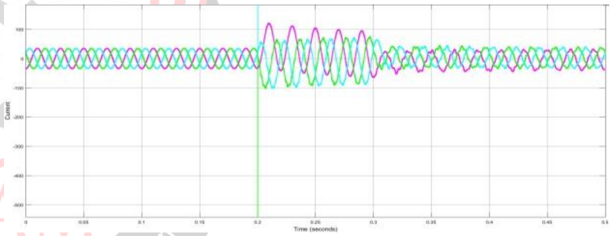

Fig.6: 3- Φ line current without D-STATCOM mitigation

A 3-Φ fault, as depicted in Figure 6, occurs during a transition phase of t = 0.2s to 0.3s, during which the line current is going to experience considerable fluctuations. The fault impact may cause the line current to suddenly spike at t=0.2s. Due to continuous variations, the line current may reach peak values at t=0.2–0.3. The line current may finally settle after t=0.3, but it may also briefly oscillate before going back to normal.

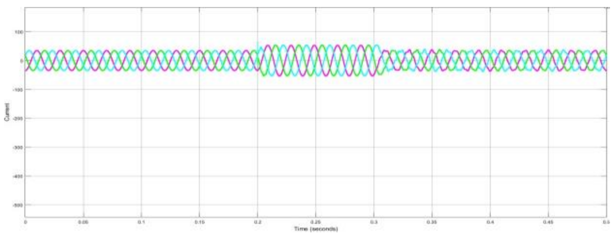

Fig.7: 3- Φ line current with D-STATCOM mitigation

When DSTATCOM is connected to the system in Figure 7 at t=0.2 seconds, it will continue to maintain the voltage stability which impacts the line current. The line current

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will be less prone to unexpected spikes or swings at t=0.2s-0.3s time interval. The line current will be more stable and under control after the voltage is controlled by the DSTATCOM beyond t=0.3s.

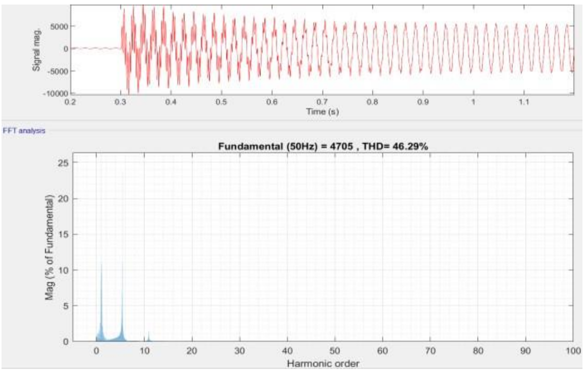

Fig.8: THD of Load voltage without D-STATCOM compensation

THD spectrum measurement of the load voltage is used to evaluate power quality. According to Figure 8, there is harmonic distortion present since the load voltage's THD is high—up to 46.29%—in the absence of D-STATCOM.

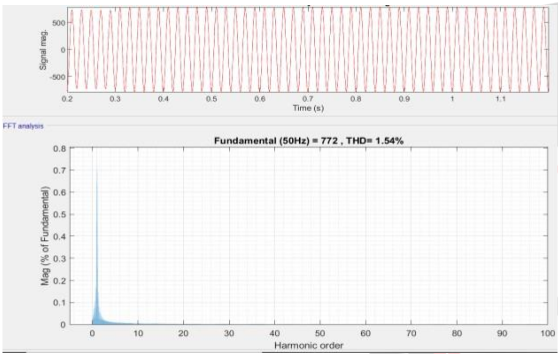

Fig.9: THD of Load voltage with D-STATCOM compensation

In Figure 9, the system that will significantly lower the THD to 1.54% is connected to D-STATCOM.

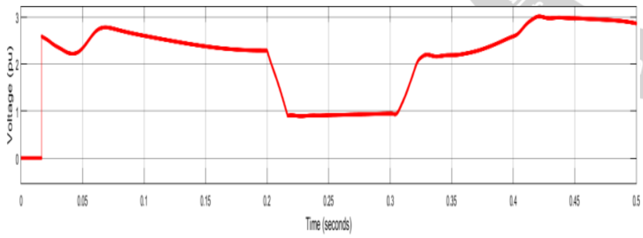

Fig.10: Line voltage magnitude without DSTATCOM mitigation

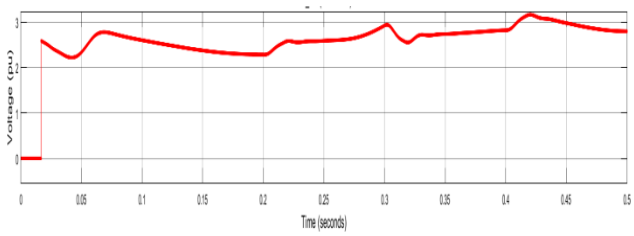

Fig.11: Line voltage magnitude with DSTATCOM mitigation

The system experiences a significant drop in line voltage magnitude during a 3-Φ fault, as depicted in Figure 10, which occurs within a transition period of t = 0.2s to 0.3s. Figure 11 shows how D-STATCOM is attached to the system to maintain it and reduce the magnitude of the line voltage.

D-STATCOM PERFORMANCE DURING 2- Φ FAULT

A fault is caused for voltage sag 2-.Φ Faults of different resistance are formed because the length of the sag depends on the fault resistance. The line voltage, line current, line voltage magnitude, and line voltage's total harmonic distortion (THD) are all included . The load parameters of the system are determined by R=0.33 Ω and L =0.52 H. The 21 kV energy device's D-STATCOM is investigated as follows:

A 2- Φ fault is made at point A via a transition time of 0.2s to 0.3s for the resistance of 0.50 Ω and D-STATCOM is not been connected to the system, which would cause voltage sag 33.2%. After D-STATCOM is connected, voltage sag improves to 4%. THD spectrum of the load voltage improves from 36.58% to 1.79%.

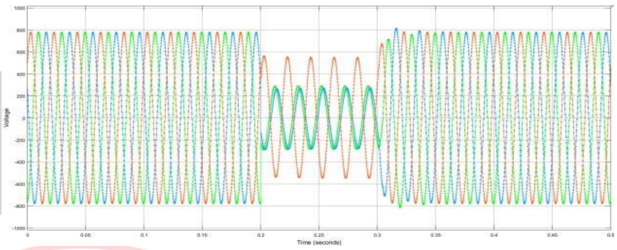

Fig.12: 2- Φ line voltage without D-STATCOM mitigation

As shown in fig.12, A two-phase fault is created, and the fault resistance (Rf) determines how long the sag will last. When the fault resistance is 0.50 Ω, the sag period varies between 0.2 to 0.3 s. The voltage sag is 33.2% prior to the D-STATCOM being attached to the system. This large sag may be harmful to processes and equipment that are sensitive.

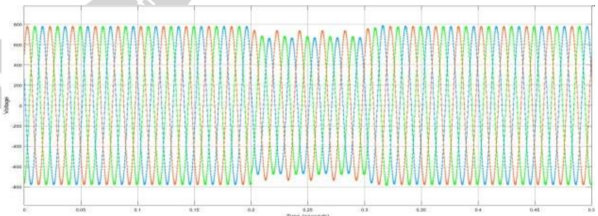

Fig.13: 2- Φ line voltage with D-STATCOM mitigation

As shown in fig.13, After connecting the D-STATCOM the voltage sag improve up to 4%. This show that D-STATCOM successfully compensate the voltage drop which is caused by the fault.

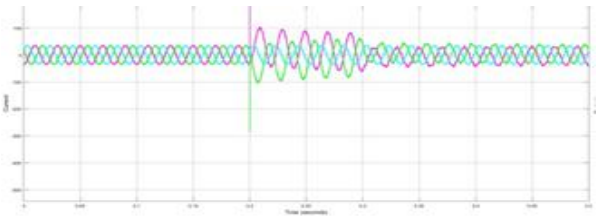

Fig.14: 2- Φ line current without D-STATCOM mitigation

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A 2-Φ fault, as depicted in Figure 14, occurs during a transition phase of t = 0.2s to 0.3s, during which the line current is going to experience considerable fluctuations. The fault impact may cause the line current to suddenly spike at t=0.2s. Due to continuous variations, the line current may reach peak values at t=0.2–0.3. The line current may finally settle after t=0.3, but it may also briefly oscillate before going back to normal.

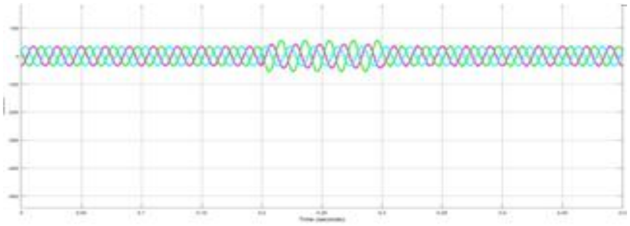

Fig.15: 2- Φ line current with D-STATCOM mitigation

When DSTATCOM is connected to the system in Figure 15 at t=0.2 seconds, it will continue to maintain the voltage stability which impacts the line current. The line current will be less prone to unexpected spikes or swings at t=0.2s-0.3s time interval. The line current will be more stable and under control after the voltage is controlled by the DSTATCOM beyond t=0.3s.

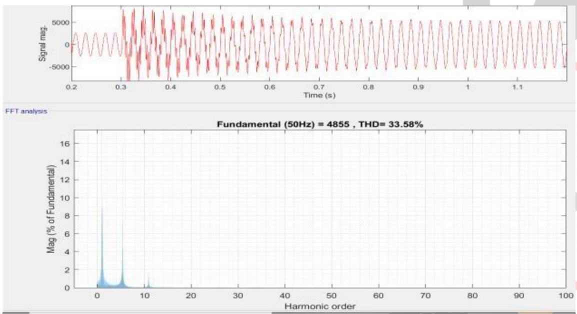

Fig.16: THD of Load voltage without D-STATCOM compensation

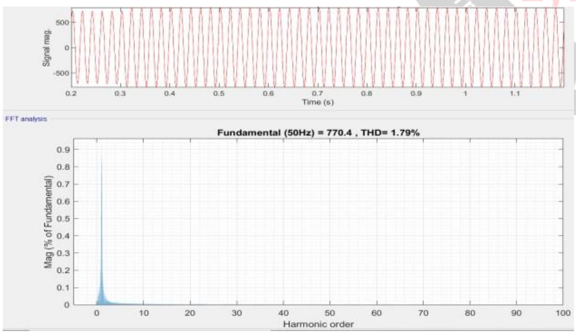

Fig.17: THD of Load voltage with D-STATCOM compensation

THD spectrum measurement of the load voltage is used to evaluate power quality. According to Figure 16, there is harmonic distortion present since the load voltage's THD is high—up to 36.58%—in the absence of D-STATCOM. In Figure 17, the system that will significantly lower the THD to 1.79% is connected to D-STATCOM.

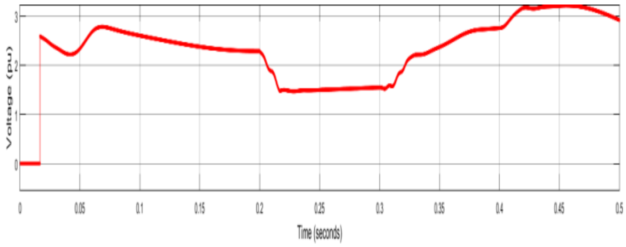

Fig.18: Line voltage magnitude without DSTATCOM mitigation

The system experiences a significant drop in line voltage magnitude during a 3-Φ fault, as depicted in Figure 18, which occurs within a transition period of t = 0.2s to 0.3s. Figure 19 shows how D-STATCOM is attached to the system to maintain it and reduce the magnitude of the line voltage.

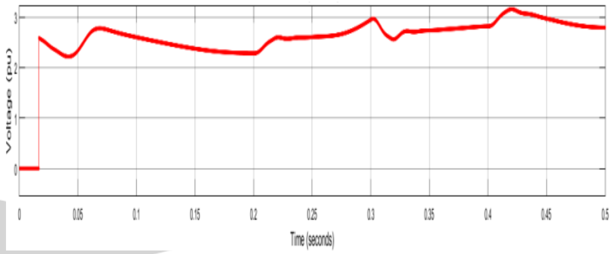

Fig.19: Line voltage magnitude with DSTATCOM mitigation

The results from analysis of the above single phase to ground fault condition validate that the D-STATCOM successfully mitigate the voltage sag considerably. For long duration voltage sag is suited to compensate about 25.6% to 4.5% sag and 22% to 2.78% with a decent efficiency. Thus, the proposed DSTATCOM design finds its utility in distribution system particularly.

From analyzing the 2- Φ faults and 3- Φ faults in the transmission system it would be concluded that D-STATCOM is an excellent custom power device for the mitigation of voltage sags and total harmonic distortion into the interrupted system. By the use of this model there are excellent performance on the load side components, improved reliability and stability and good voltage profile.

VI. LIMITATION AND DRAWBACK

Reactive Power and Power Factor: Reactive power and power factor issues might occur from the load characteristics of the system, which are shown by R = 0.3 Ω and L = 0.486 H. Reactive power modification is also probable to be necessary. The load parameters may not be appropriate for all kinds of loads and can end up in problems with power quality.

(a) **Voltage Drop:** Resistive and inductive losses during the long-distance transfer of electrical power, particularly in a 150 km transmission line, can cause voltage drop. This could require more voltage control processes and result in problems with power quality at the load end.

(b) **System Sizing and Tuning:** It might be difficult to size and tune DSTATCOM systems appropriately for a particular distribution network. It's possible that a

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DSTATCOM that is insufficient or incorrectly configured won't produce the expected increases in power quality and stability.

(c) **Expense and Execution Complexity:** It can be costly to integrate DSTATCOM into an existing grid. Equipment, installation, and continuous maintenance may all be expensive. Widespread adoption of such systems may be hampered by their complexity of integration, particularly into older infrastructure.

(d) **Ageing Infrastructure:** It's possible that the suggested effort will not deal with the core problem of ageing infrastructure. While upgrades can yield short-term benefits, larger financial outlays might be necessary to ensure the grid's sustainability over the long run.

VII. CONCLUSION

The study concludes that the deployment of D-STATCOM has a major impact on the development of sustainable agriculture within solar energy applications. This is because the findings of this study confirm this impact. Fault resistance has been found to have a significant impact on the amount of voltage sag that occurs under various fault circumstances. The introduction of the D-STATCOM considerably reduced the voltage sag caused by a 3-Φ fault, which was a fixed resistance of 0.50 Ω,35.9% to 5.2%. similarly D-STATCOM intervention caused voltage sag in the case of a 2-̤ fault to decrease from 33.2% to 4%. Further, the load voltage's total harmonic distortion (THD) spectrum showed significant decreases with D-STATCOM installed, dropping from 46.29% to 1.54% and from 36.58% to 1.79%. According to these results, D-STATCOM plays a crucial part in improving power quality and regulating voltage levels in solar energy applications. These advancements are extremely promising for the agriculture industry, as they ensure a more reliable and efficient energy source that supports the success of agricultural endeavours and overall sustainability.

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