
Reactive Power Control for Power System Quality Improvement Through FACT and D-STATCOM

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Abstract

The integration of distributed generation (DG) in the distribution system creates multiple challenges for engineers. The power quality is one of them. The integration of DG and the application of electronic devices in power systems is a challenge for power quality. The primary benefit of the DG system is the elimination of 50% of faults and 40% of transmission line losses. By adding reactive power and controlling it, solar and wind energy in DGs must operate better and be more efficient. Power system quality was enhanced by incorporating different techniques and parameters. In this research power quality was improved through reactive power control. Reactive power control is a major problem, especially due to the integration of DG, non-linear devices and converters. FACT (Flexible Alternating Current Transmission System) devices and D-STATCOM (Distribution Static Synchronous Compensator) are the advanced technologies to inculcate power system quality. MATLAB simulation tools were used to evaluate the results of the findings. The outperform of D-STATCOM is capable of reactive power control, reactive power compensation, power factor correction, stabilizing voltage, and reduction of harmonics either voltage or current modes operation. Active and reactive power, voltage and current were measured by incorporating the D-STATCOM at the load bus. The results show the outperformance of D-STATCOM in order to improve the voltage stability by controlling reactive power. The simulation results show the 2-second settling time when no overshoot without D-STATCOM while 0.5 seconds with D-STATCOM at 30% overshoot.

Index Terms—Distribution Generation, FACT Devices, D-STATCOM, Reactive Power Control, Power Quality.

I. INTRODUCTION

A. Overview of Study

THIS integration of DG into the power system is a future need for every country. Renewable energy like solar and wind are the major sources nowadays. The application of electronic devices in power systems leads to power system quality issues. Voltage stability is the major issue when talking about power quality. Many researches were carried out to make the power system stable like demand response techniques, optimization techniques, artificial intelligence base, probabilistic analysis and neural network. According to the findings [1], “the suggested EMS (energy management system) decreases the prosumer's operating cost and increases self-consumption, minimizes peak load from the national grid, and encourages campus stakeholders. A thermostat set point control rule is used to generate the control signals of appliances in the precise execution and make the system stable” [2]. Different probabilistic load flow analysis techniques were used to control the consumer loads [3,4]. Voltage and transient stability analysis was carried out to tackle the stability issues —[57] and DC voltage control [8]. Similarly, many studies were carried out to find the optimal placement of DG in order to reduce the power loss and economic point of view[9] and artificial network analysis techniques were presented in —[10,11].

Voltage stability denotes the power system's capability to uphold acceptable voltage levels at all nodes within the network, whether under normal operational circumstances or during disturbances [12].

This aspect is commonly related to the characteristics of loads, generators, and reactive power compensation devices. Voltage instability arises when factors like increased load demand, substantial disturbances, and changes in system operating conditions lead to an ongoing and uncontrollable decrease in voltage. The paramount importance of maintaining voltage stability within these systems cannot be overstated, as it is essential for operational reliability, preventing equipment damage, and averting power outages. To address these issues, conventional technologies like optimal feeder reconfiguration, voltage regulators, and capacitor placement have been employed effectively [13].

B. Literature Review

The voltage control strategy “multi-stage voltage control in a DG penetration distribution system based on high photovoltaic (PV) systems considering the reactive power capacity of smart inverters” involves a comprehensive approach to managing voltage levels in a power distribution system that is heavily influenced by distributed generation based on PV [14]. The optimization of reactive power in a distribution network and the skill of regulating the reactive power of a distributed energy production group consists of managing the flow of reactive power to improve the efficiency and permanence of the electrical system. Reactive power is important to maintain voltage levels within a satisfactory range and support the operation of inductive loads. Here is an overview of key components and considerations in this context [13]. Kumar, C et al. Examining the control of reactive power in renewable energy-rich power grids is a crucial aspect of power system management, aiming to address the

unique challenges associated with the integration of renewable energy sources into the grid. A literature review on this topic would generally cover various research studies, methodologies and technologies used to optimize reactive power in the context of renewable energy-rich power systems [15]. Deakin, M et al. write an article on voltage control loss factors that are parameters used to quantify the impact of DG reactive power control on system losses and reduction of a distribution network electricity. These factors help evaluate the effectiveness of reactive power control strategies in managing voltage levels, reducing losses, and minimizing curtailment of distributed generation [16]. The concept of “reactive power compensation using the derated power generation mode of a modified Disturbance and Observation (P&O) algorithm in a grid interfaced PV system” involves a specific approach to control the reactive power of output of a photovoltaic system connected to the grid. An analysis of the active power and reactive power control approach for renewable energy production systems, which involves the development of methods and algorithms to effectively control both the active power and reactive power from renewable energy sources. This strategy is crucial for network integration, stability and overall system reliability [17]. The analysis of voltage and reactive power optimization in distribution networks with DG involves the development of control strategies to maintain voltage levels within appropriate limits and regulate power flow reactive. Basic linear equations can offer a computationally efficient approach to achieving this optimization.

The voltage and reactive power control processes in electrical distribution networks involve examining various methodologies and strategies designed to regulate voltage levels and manage the flow of reactive power within the distribution network. This review encompasses a wide range of control techniques, from classical methods to more advanced and adaptive algorithms. The reactive power reward techniques in microgrids which study the DG system based on inexhaustible energy have been the problem-solving and solution for researchers to combat the problems of increasing power demand load in the electrical system [18]. The reactive power control in the case of extensive connection of distributed generators to the power grid which is studied in this research article discusses the modern discovery of constraints and problems at the transmission and distribution (TD) level. when the DG masses are cracked with different inspections. Lubanj ar et al. explained the system based on fuzzy logic reactive power control, in the radial feeders studied in this research topic, which manage the reactive power of the radial feeder using fuzzy logic controller (FLC) techniques. The hybrid STATCOM solutions in renewable systems study the dynamic behavior of the renewable power plant for the grid requirements regarding V and Q components. The design and implementation of flexible power interfaces for distributed generators, this research describes a new technique for designing power plant interfaces connecting the DG to the distribution system network [19].

The fuzzy logic method for controlling the reactive power of wind turbines to control the reactive power of wind turbines using the technique of a fuzzy logic control system in the power grid. The modelling and optimal control of reactive power in a microgrid system which studies the control of reactive power based on Particle Swarm Optimization (PSO) method by minimizing the function of cost [20]. The civilization of the future involves a new prototype in the way the

world will work, a new thing, new notions like smart homes, smart grids, smart cities and smart villages. and their interaction has been permanent. The real-time power control algorithm for standby reactive power of wind farms, which studies the reactive control of reactive power, has not been implemented in the wind control framework, because the owners of the unlimited control framework supervise the genial control in the framework and maintain the tension precondition. The reactive power controller for DG grid-connected systems which study the power electronics interface with decentralized distributed generation and inductive load. Wang et al. explained the active and reactive power control systems for distributed generation systems under voltage slope in this article amidst voltage sags, the non-stop transmission of DGs to the grid is attractive for rear framework reasons [21].

C. Research Contribution

The proposed technique D-STATCOM has outperformed itself in order to control reactive power in distribution systems on other techniques presented in the literature. This device can control and compensate for voltage as well as current. It can be operated in voltage as well as current mode. D-STATCOM working in two modes of operation. Firstly, when the bus voltage magnitude (VB) is greater than the reference bus voltage (V_{ref}). It will work in inductor mode. It means, it will draw reactive power from the power system to stabilize the voltage. Secondly, When the bus voltage magnitude (VB) is less than the reference bus voltage magnitude (V_{ref}). It will inject reactive power into the system to stabilize the voltage. Overall, in first mode of operation it act as inductor. In the second mode of operation, it acts as a capacitor. Due to the above surplus advantage of the proposed technique, this technique is applied to evaluate the results.

II. METHODOLOGY

A. Modern Power System

In the state-of-the-art perception of power system complete in one stage of power system. The new technology power generation allows to a small size of generation and do not require any high-level insulation. The new small size of generation depends on renewable energy. The inexhaustible energy resource is rising periodically to improve the environmental impact of power systems. Fig. 1 represents the modern power flow model.

B. Flow Chart

The flow chart of the proposed study is presented in Fig. 2 that shows the control of reactive power by incorporating the D-STATCOM.

C. D-STATCOM Modelling

D-STATCOM is a shunt connected device. It is designed to manage the voltage either by generating or consuming from the system. The Basic block model of a D-STATCOM is presented in Fig. 3. It contains.

- DC Capacitor
- Voltage Source Inverter (VSI)
- Coupling Transformer
- Reactor

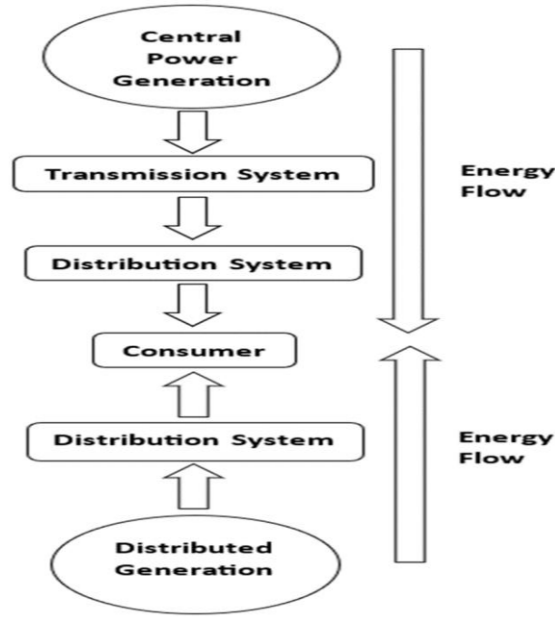


Fig. 1. Modern power system with distribution generation

The voltage source inverter generates voltage by receiving the input voltage from the accumulative capacitor or charging bank of the capacitor. In this purpose of invention to use plus width modulation (PWM) switching technique. This voltage is transformed to the system by coupling transformer. The voltage distinction across the coupling transformer reactance is employed to give the reactive and real power exchange b/w load and D-STATCOM. This method of improving of reactive power is done much like a synchronous condenser and improves the system performance.

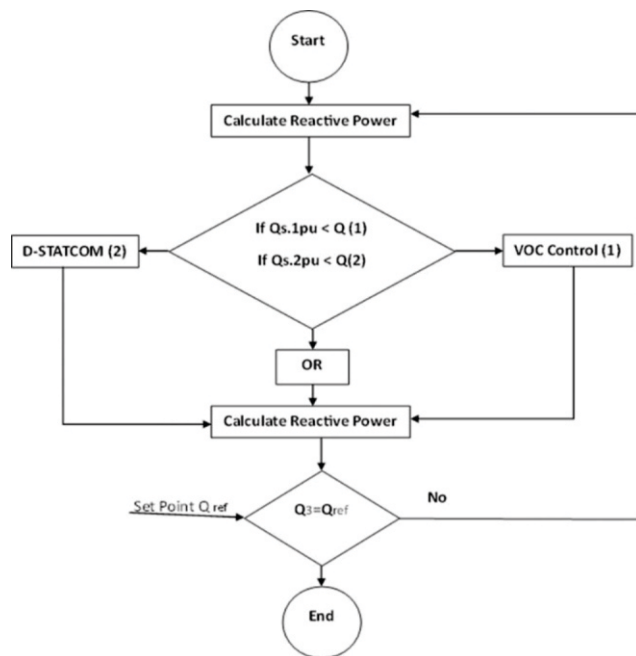


Fig. 2. Flow chart to control reactive power

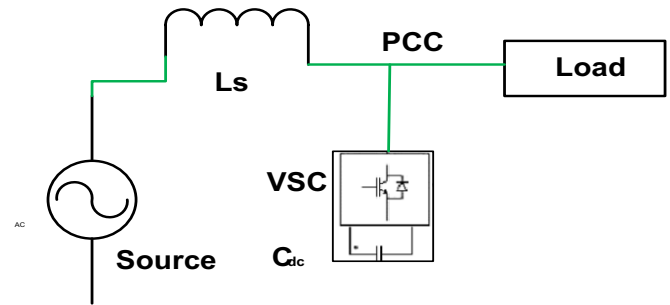


Fig. 3. D-STATCOM Basic Model

Operating Principle

The device of D-STATCOM capable of controlling and compensating either bus voltage or as well as its line current. It has two methods to operation principles.

- **Voltage Operation:** the mode of operation, it will raise the bus voltage. This could be achieved regardless of the distortion within the offer voltage.
- **Current Operation:** the mode of operation, the D-STATCOM try to inject the supply current to be a balanced sinusoid. It will free from the load current harmonics.

In D-STATCOM the reactive power mitigation to control the reactive power of bus. Therefore, the D-STATCOM acts either as an inductor or as a capacitor. It will depend upon the magnitude of the bus voltage and Q-Power.

- **Inductive Operation:** D-STATCOM working in two modes of operation. Firstly, when the bus voltage magnitude (V_B) is greater than the reference bus voltage (V_{ref}). It will work in inductor mode. It means, it will draw reactive power from the power system to stabilize the voltage.
- **Capacitive Operation:** When the bus voltage magnitude (V_B) is less than the reference bus voltage magnitude (V_{ref}). It will inject reactive power to the system to stabilize the voltage.

D. PV Design

Two diode models of PV array for DG system are presented in Fig. 4. Fig. 5 shows the result of solar cell current in range of 7-7.5 ampere. Fig. 6 shows the solar cell voltage result in range of 31.21-31.28 volts.

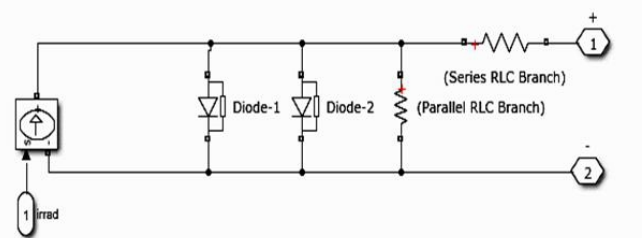


Fig. 4. PV model for two diodes

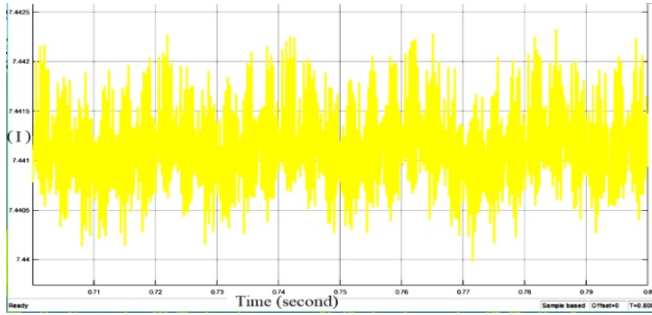


Fig. 5. Solar cell current result

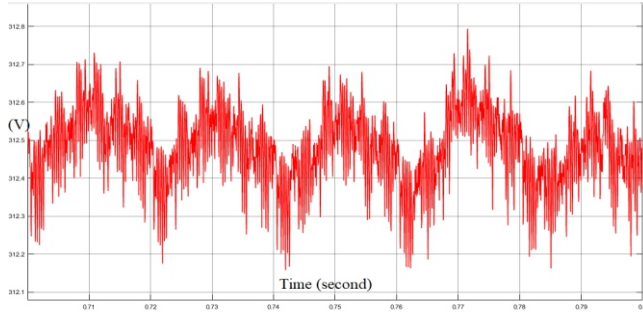


Fig. 6. Solar cell voltage result

E. D-STATCOM Simulation Model

Fig. 7 shows the simulation model of D-STATCOM. The simulation model makes by using an inverter/converter set. Bridge-1 use as rectifier and bridge-2 use as inverter and produce 3-Phase AC supply. The control simulation block shown in the model may be controlled and work in during change of reactive power.

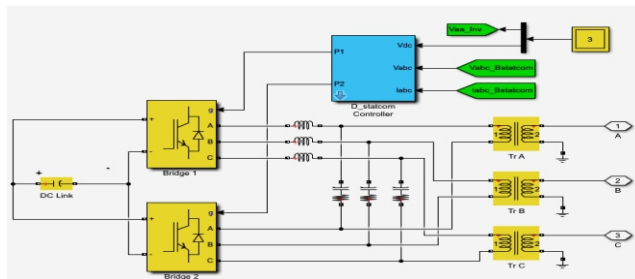


Fig. 7. D-STATCOM simulation model

F. D-STATCOM Controller

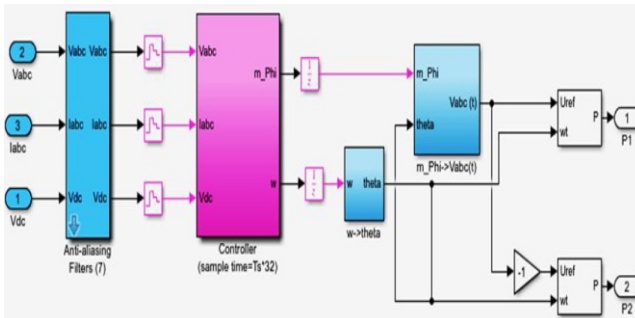


Fig. 8. D-STATCOM controller diagram

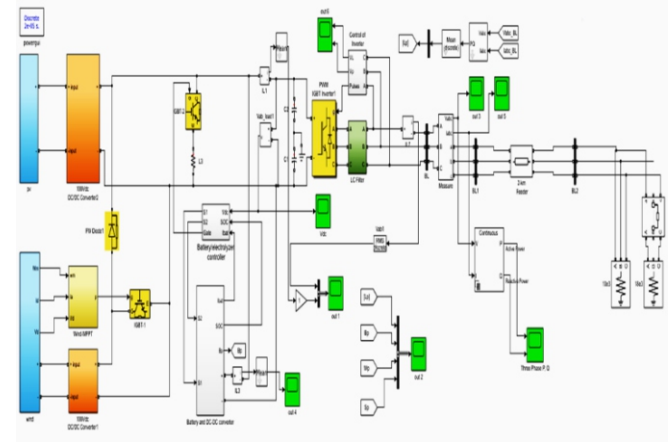


Fig. 9. SG system simulation without D-STATCOM

Fig. 8 shown the simulation diagram of D-STATCOM controller. V_{abc} , I_{abc} and V_{dc} use the reference value to control the reactive power of inverter bridge.

III. RESULTS AND DISCUSSION

A. DG System Simulation without D-STATCOM

Fig. 9 shows the SG system simulation model without D-STATCOM and with internal control torque. This model is made by using two renewable energy resources, wind energy and solar energy resources. The wind energy varying reactive power and solar energy varies the active power due to this condition all energies convert into DC level. IGBT inverter use for converting the DC into AC level. It is produced 380V AC.

Fig. 10 shows the output result of three phase voltage of DG system. The output result of voltage may be shown in a sinusoidal three phase wave but harmonics present in the wave form.

B. DG System with D-STATCOM

Fig. 11 shows the hybrid model of renewable energy resources with D-STATCOM. The simulation model is made in MATLAB Simulink. The model showed the complete working of the hybrid model and D-STATCOM control the reactive power of load bus as well as inverter, but inverter internal control technique works with parallel in D-STATCOM. The variation of wind energy control by DC bus and wind MPPT. The variation of real power in solar energy control by boosting converters with the help of DC power bank.

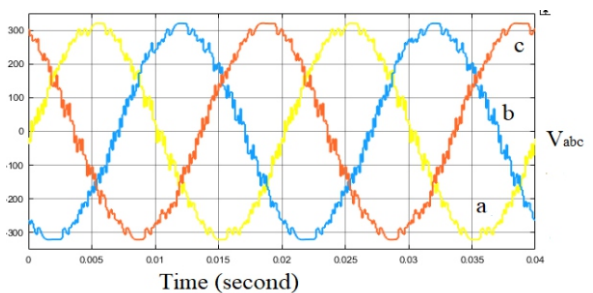


Fig. 10. Three phase output voltage from DG system

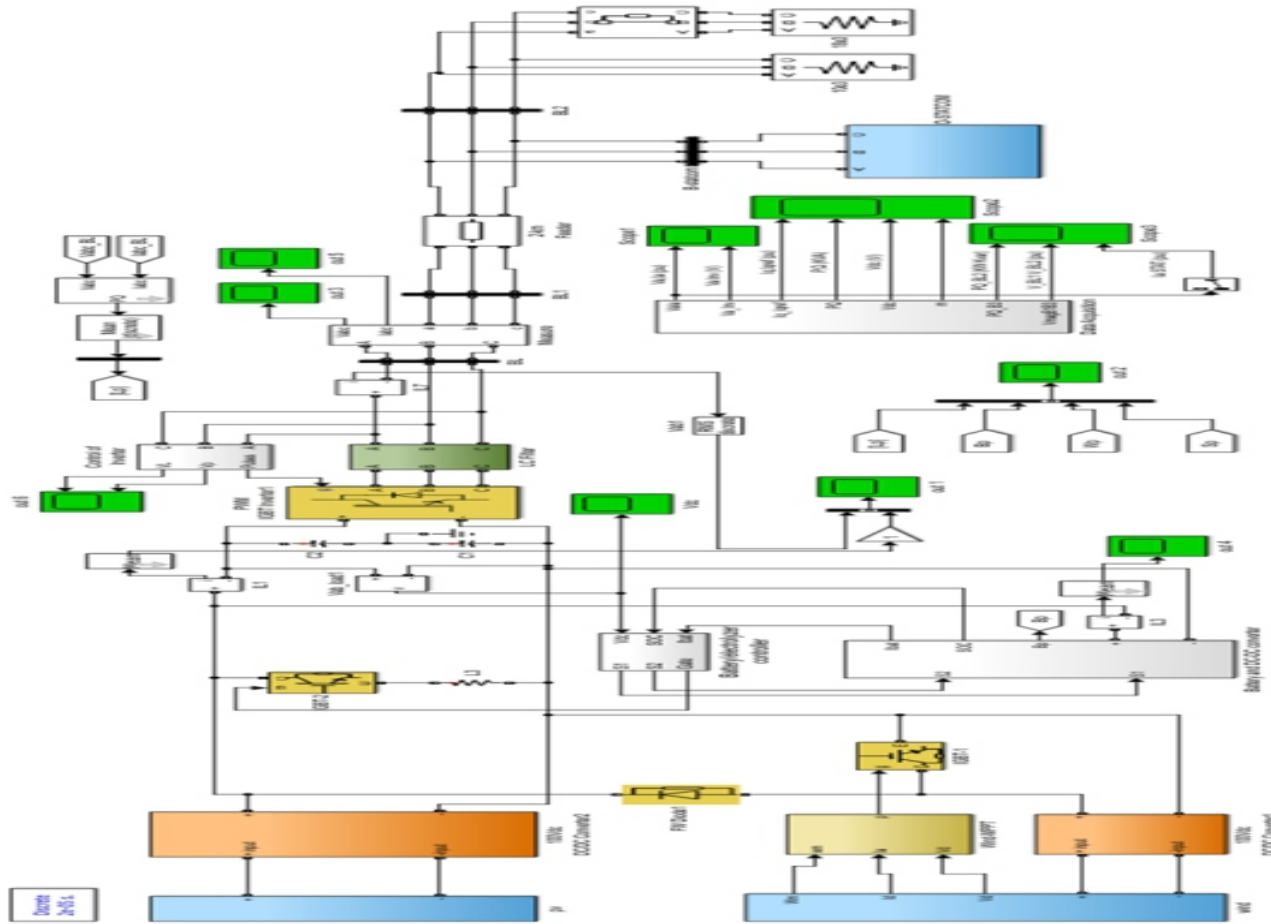
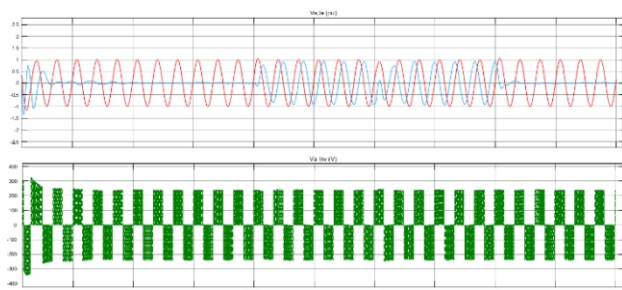


Fig. 11. SG system model with D-STATCOM

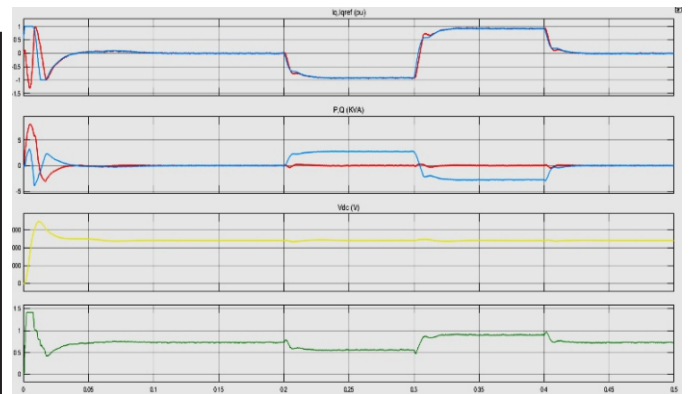
C. Simulation result V_a and I_a


 Fig. 12. simulation result of V_a and I_a

The above Fig. 12 shows the result of V_a and I_a . The display one shows the result of V_a and I_a after improving the stability of the DG system by using the D-STATCOM control. The stability of voltage control by controlling the system reactive power. The display two shown the DC level of DG system.

D. Simulation results of P , Q , and V_{dc}

Fig. 13 shows the P and Q measurement by reference value, the


 Fig. 13. Simulation result of P , Q , and V_{dc} measurement

reactive power of load control by FACT device D-STATCOM control. It controls the reactive of DG system as well as the voltage of DG.

E. Simulation result of load bus

Fig. 14 shows the result of active (P), reactive (Q) power and with D

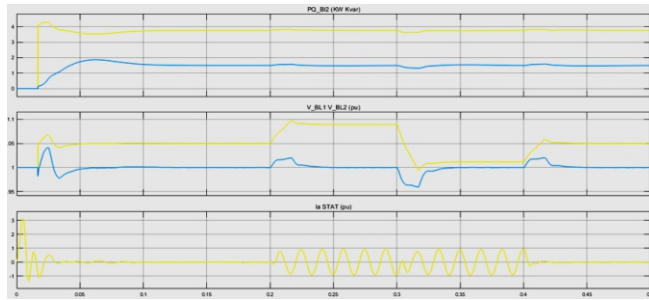


Fig. 14. P, Q and V measurement at load bus

-STATCOM measured on load of bus. The results show the improvement of the quality of voltage by controlling the reactive power at load bus by incorporating D-STATCOM in DG system.

F. Comparison of the results

Table I shows the comparison of results with and without D-STATCOM. From the results it clearly shows that the settling time is 2 sec without D-STATCOM while the system has no overshoot. When using D-STATCOM in DG system the settling time is 0.5 sec while overshoot is 30% that is balance and acceptable limits.

V. CONCLUSION

Poor power quality is a common problem in DG integrated into power systems. To tackle this problem many control techniques were discussed in literature including but not limited to optimization of devices, demand control, artificial network, probabilistic load flow analysis etc. In this article, FACT and D-STATCOM technology was adopted to overcome the problem of poor power quality, especially voltage quality. The reactive power control technique was adopted to control the voltage stability in a DG distribution network. Due to the outperformance of D-STATCOM to control the reactive power in DG distribution network to improve voltage stability. Overall, D-STATCOM has the potential to enhance voltage stability by injecting reactive power into the system, and the insertion of more than one D-STATCOM can significantly improve the loading factor, voltage profile, and reduce power losses. D-STATCOM working in two modes of operation. Firstly, when the bus voltage magnitude (V_b) is greater than the reference bus voltage (V_{ref}). It will work in inductor mode. It means, it will draw reactive power from the power system to stabilize the voltage. Secondly, when the bus voltage magnitude (V_b) is less than the reference bus voltage magnitude (V_{ref}). It will inject reactive power into the system to stabilize the voltage. Overall, in the first mode of operation it acts as an inductor. In the second mode of operation, it acts as a capacitor. The results clearly show that the settling time is 2 sec without D-STATCOM while the system has not overshoot. When using D-STATCOM in the DG system the settling time is 0.5 sec while overshoot is 30% that is balance and acceptable limits. Additionally, the harmonics are also eliminated from the

TABLE I comparison of simulation result

Case	Over Shot	Settling Time	System Condition
Without D-STATCOM	No over shot	2 sec	Un-acceptable/Un -balance
With D-STATCOM	30%	0.5 sec	Acceptable/ Balance

system with apply the D-STATCOM. In future work, this device DSTATCOM can be used to tackle power-quality issues by providing power factor correction, harmonic elimination, load balancing, and voltage regulation based on the load requirement.

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