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Numerical Simulation and Design for Mitigating Power Quality Issue based on PV Supported DVR and D-STATCOM

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Abstract: Integration of the grid with non-conventional energy systems has always been a difficult scenario, but with conventional energy depleting at an alarming rate and power demand rising by the day, it has become imperative to concentrate on renewable energy systems and their integration with the conventional system. Little attention has been paid to the integration of Renewable Energy Sources (RES) into the existing Power System to meet the growing demand for electricity and improve the related power quality issues. Power quality issues and their significant influence on sensitive loads are well-known. By integrating a solar PV integrated Static Synchronous Compensator (PV-STATCOM) and PV-battery based Dynamic Voltage Restorer (DVR) into the grid, the proposed study aims to compare the performance of both the devices to improve power quality issue. The maximum power output from a PV array is retrieved using a P&O MPPT controller, regardless of temperature or irradiation conditions. The PV- STATCOM's and DVR's DC-link is connected to solar PV via a DC-DC boost converter. MATLAB SIMULINK has been used to model and simulate PV integrated DVR and STATCOM. The PI controller and discrete PWM provides the control of DVR and PV-STATCOM. According to the simulation results DVR is more efficient than D-STATCOM for improving power quality in PV integrated grid.

***Keywords:** RES, PV-STATCOM, DVR, D-STSTCOM, PWM.*

1. INTRODUCTION

The enhancement of low-cost renewable energy technologies, such as solar, wind and fuel cells, has encouraged them to become alternative energy sources in the future. It does however create technical challenges such as voltage control, voltage flicking, total harmonic distortion, variable output of the system stability depending on environmental conditions. By integrating the RES into the utility grid the adverse effects can be reduced. [1] However, integration of these renewable energies into the grid causes serious changes in the grid power flow, which affects the energy management system.

To take the utmost advantage of renewables we need to integrate them in PS. Though technologies have been developed to produce power from renewable sources but there is a lot to explore about their integration in existing Power System. There are many challenges faced by utilities in the process, the main being the fluctuation of power supply. As we are aware that the availability of the renewable energy like solar and wind is unpredictable and intermittent and we need to balance the energy generation with the demand so we need additional energy. Existing distribution system which is unidirectional is to be made bidirectional leading to the advancement of smart grid technology. The complexity of the grid increases. Problem of storage of power produced by RES cannot be ignored. The voltage and frequency have to be controlled for the stability of the grid. Optimal cost is also to be considered. The other problem is the fact that these sources are concentrated regionally i.e., they cannot be made available everywhere.

A grid-connected solar PV system is an energy inverter that converts DC current from a PV module into alternating current. If the PV panel is coupled to the grid it can transmit excess energy to the grid after meeting the limited demand. If demand exceeds supply, however, additional energy is provided from the grid[2]. As a result, PV energy serves as a secondary source of electricity. One is to elevate the DC-DC Converter's pv modules voltage to a level higher than the highest voltage level. Electricity Converters are used to connect the RES to the power system.

Due to new energy and incentive policies, residential consumers are growing more interested in deploying single-phase grid-connected solar cells in a variety of nations. The basic feature of the PV is its uncontrollable power output that depends on the immediate energy of the solar energy. Rooftop PVs are often randomly dispersed between domestic customers of the network. Due to the uncertainty of power of the customers' PV placement, voltage imbalances in the system would increase.

The first is used as "Off-grid" and the second as a Solar PV-System "Grid Connected." Photovoltaic systems are independent and separate in the off-grid photovoltaic system, so they are not connected with the main electrical power or the distribution system. In contrast, the 'Grid Connected' PV solar system is plugged into the national grid or the supplier of electricity. The main difference is the storage device. Photovoltaic out-of-grid systems are batteries that store extra energy produced during peak hours where excess energy is sold to the power transport company, such as the grid-connected photovoltaic system.

The power generated by conventional power generators such as synchronous generators meets demand in today's electricity system. Any change in demand can effectively maintain the stability of the systems by providing high-rotor inertia with the difference power from the stored energy. In the future, however, the power must be dynamically tracked to maintain system stability for intelligent grids with high penetration of the distributed source of renewable energy without inertia. This new requirement has brought modern demand side management to the attention of researchers.

2. OBJECTIVE

In this paper, an innovative approach for mitigation of power quality disturbances in renewable energy interfaced hybrid power grid is proposed. By integrating a solar PV integrated Static Synchronous Compensator (PV-STATCOM) and PV based Dynamic Voltage Restorer (DVR) into the grid, the proposed study aims to compare the performance of both the devices to improve power quality issue. A P&O MPPT controller would get the maximum power output from a PV array, regardless of temperature or irradiation conditions. The PV- STATCOM's and DVR’s DC-link is connected to solar PV via a DC-DC boost converter. MATLAB SIMULINK has been used to model and simulate PV integrated DVR and STATCOM. The PI controller and discrete PWM provides the control of DVR and PV-STATCOM.

3. LITERATURE REVIEW

Electricity production is the primary part of industrial air pollution. Coal, nuclear, and other non-renewable power plants provide the majority of power. Our environment, air, land and water, is severely affected by the production of energy from these resources. RES can create electricity with little environmental consequences. Electric power can be created from renewable power without even emitting CO2, which is the primary driver of global warming.

These resources also have the advantage of being plentiful, accessible practically anywhere, and causing little, if any, environmental damage. The light from the sun energy can be stored in the Earth's surface, as well as thermal and wind energy. In contrast, fossil fuels like coal, petroleum, and natural gas are non-renewable because their quantities are limited, because they are no longer available as an affordable source of energy once we have extracted them. Because the mechanisms of their generation are too delayed to renew such fuels at the same rate that humans utilise them, they will eventually run out.

Given increasing RE-penetration, it is critical for further variability and uncertainty to ensure system flexibility in multiple time frames. With functioning reserves fallback, and safety evaluations, conventional power systems handle consumption and system breakdowns in an uncertain manner. RE increases existing unpredictability and uncertainty on a large geographic and temporal scale, necessitating a faster reaction from network resources. While the necessity of flexibility in increasing RE penetration is acknowledged, identifying adequate technological choices for a national electricity system remains difficult.

The dynamics of large-scale power systems are rapidly evolving due to the increasing penetration of distributed energy resources (DERs) and their displacement of traditional synchronous generators (SGs). Inertia, voltage support, and oscillation damping are all lacking in electric grids. In any power system, there must be a balance between active power generation and consumption, or the system will experience frequency variance. The system inertia controls the frequency deviation at first by releasing or consuming the kinetic energy of rotating generating sets and motors linked to the system [6]. However, inertia has decreased as the penetration of renewable resources, especially wind and solar systems, has increased[7].

The closest PV arrays are to a central station, the more power fluctuations can occur during cloud shading, necessitating the use of additional frequency control services[8]. It's worth noting that the power system's overall inertia is proportional to the initial rate of change in frequency and is dictated by the system's overall inertial response of all generating units.

DRG’s have several negative effects on the bulk power system. In the meantime, lower or zero inertia is one among the most important factors that influences the total reliability of the power system and may result in unwelcomed load shedding [9]. The solution is to adding inertia to DRGs by imitating synchronous generation behaviour.

Due to a rise in connected load that uses power electronic converters, renewable energy sources are becoming more common at the distribution level. Disturbances in the electrical power network arise as a result of the widespread use of power electronic devices. Non-linear systems are to blame for these annoyances. Harmonics will be generated in the power supply, triggering equipment to explode and appliances to be damaged. Active Power Filters (APF) are used to adjust for current harmonics and load imbalance [10].

Solar insolation varies, as does geographic location of PV systems cause output power variability. It's worth noting that a small difference between grid and PV system voltages will result in an exponentially declining inrush current flowing between the power grid and the PV system, which can cause difficulties like nuisance tripping and overheating . Harmonic resonance does become a serious problem at the connecting point due to the impedance mismatch between both grid and the inverters due to the significant deployment of PV in the electric grid. Harmonic resonance can result in major power quality problems, such as protective system tripping/failure and unexpected over-voltage/over-current, that can damage vulnerable equipment

According to research, as PV penetration climbs, the harmonic connection between the dispersed network and numerous PV units grows considerably.

Due to the variable production of PV systems, maintaining a steady supply of electricity becomes a difficult issue for the power system's functioning. Traditional generators will be replaced by large PV systems or extremely high penetration levels, improving the damping ratio and minimising oscillations of PS. Therefore, some critical synchronous generators must be kept online to ensure that sufficient damp system is maintained.

Short-circuit current distribution can result in a quick reaction of the grid protective devices when the PV plant's capacity is high enough in comparison to the distribution grid capacity. PV power may change the magnitude, length, and direction of the fault current, or indeed amusement of the fault current, according to this fact.

The control systems and their synchronisation are impaired in a system where a large amount of SGs are displaced by RES.SGs have a fault current of 5–10 times the nominal current, whereas inverter-based systems have a fault current of approximately 2 times the nominal current, which decreases with time. This could prevent inverter-based systems' defensive relays from detecting fault conditions [11].

To develop national power systems, it is crucial to optimise the RE capacity, location, timing and planning of the introduction of versatile resources over time over a long time period. Usually, these tasks are done to fulfil some policy interest as part of long-term planning. With regulated reserve from consumption and unit failure, the present power system structure can manage a level of fluctuation and unpredictability. Only a limited amount of RE penetration can be supported by adjusting the system's operating procedure. Major economic planning is necessary in addition to operational adjustments with the broad introduction of generational uncertainty and variability [12].

The planning of the RE-centric site is also important because individual RE-generator experience statistical variations due to the spatial grouping of RE-generator, across a large region via the energy grid, that are significantly reduced by the challenges of integration [14]. In this respect, substantial planning is necessary relating to the location of RE plants, the establishment of transmission lines, collaboration between balancing agencies in different areas.

The changing output of power plants has a considerable impact on the power operation due to the intermittent nature of RES. Consequently proper scheduling of distributed generation, weather forecasting and scheduling in order to meet characteristics of load in active distribution networks should be carried out. Renewable energy errors or the load forecasting can cause uncertainties in the microgrid's real times. With solar photovoltaics systems distributed over a large area, for example, all of the photovoltaic panels may not be receiving solar radiation in the same way which results in uncertainty.

4. THREE PHASE SOLAR PV GRID INTEGRATED DSTATCOM

The function of PV-STATCOM is similar to smart PV inverter. Before understanding the operation of PV-STATCOM , knowledge of STATCOM is required. STATCOM is shunt connected reactive power compensation device which can generate or absorb reactive power. It is uses voltage-sourced converters to absorb or supply of reactive power [21]. It can be used for dynamic voltage control, voltage flicker mitigation [22]. PV-STATCOM is similar to STATCOM only difference is that DC battery is replaced by the solar panels supplying power.

DSTATCOM is a synchronous voltage generator which can supply capacitive and inductive reactive powers without any interuption. It is a shunt device which can mitigate PQ issues related to voltage and current. Some commonly occurring PQ disturbances which affcets the function of electric devices of the consumer are voltage sags and momentary interruptions. PQ problems exists because of the installation of nonlinear loads like arc furnaces and welding machines. The distribution network is also harmed by voltage flicker and harmonic problems. Many devices have been developed to help decrease the effect of these PQ problems on the power grid. Custom power devices are normally classified as power electronic equipments with a voltage rating of up to 38 kV that are used in distribution networks to improve reliability and PQ. Transformers, power converters, Static switches power inverters, Static switches injection, energy-storage modules, and master-control modules are examples of these devices. In a distribution service network, they can also perform functions including current interruption and voltage control.

Principle of Operation

A DSTATCOM is responsible for managing the reactive power. Its network is shown in Figure 4.2 , a VSC has been interconnected to a utility bus through coupling transformer. A DSTATCOM appears to be a ‘modifiable voltage source’ i.e. shunt reactors and capacitor banks are not used for VAr absorption and generation which makes DSTATCOM a compacted proposal. The interaction of reactive VAr between AC system and the converter can be regulated by altering the magnitude of the output voltage of the converter. When the output voltage of the converter is more than that of the utility bus than DSTATCOM supplies capacitive reactive power. And if the converter's output voltage is lower than the utility bus the converter supplies inductive reactive power.

V-I Characteristics of DSTATCOM

The STATCOM can give both inductive and capacitive compensation, and it can also regulate its output current independently over the rated maximum inductive or capacitive range. It can almost be completely independent of the device voltage produce the highest performance of capacitive generation (At lower voltages, a constant-current output is possible). This quality is especially of the help when the STATCOM is required to maintain device voltage during and after faults, where voltage breakdown would normally be a limiting issue. If the STATCOM is equipped with the energy-storage system of sufficient size, any combination of kW absorption or generation with var absorption or generation is possible, as shown in Fig. 1. Highly efficient control methods for adjusting real and reactive power output may be created with this capacity in order to increase dynamic and transient device stability limitations.

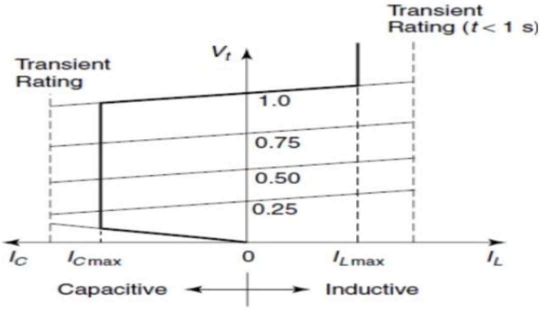

Figure 1: V-I characteristic of a STATCOM

PV-STATCOM

We know that PV-System uses VSC to convert DC power into AC power and STATCOM uses VSC to supply reactive power. So, PV inverter can also be used as a STATCOM which supplies active power along with reactive power.

Photovoltaic Solar Farm PV-Statcom is a FACTS-like controller for voltage management, PF improvement, current harmonic mitigation and VAr compensation comparable to STATCOM [23]. The DC condenser voltage is kept constant and triggers and reactive power in the proposed PCC device on a continuous basis to boost PQ both during the day and at night. The proposed grid systems are also available for the purpose of loading and unloading power fluctuations.

Modes of Operation of PV-STATCOM

The PV-STATCOM operates in modes [24]:

a) Full PV mode: The PV-STATCOM contributes real power only and no reactive power is available. This is identical to the function of conventional PV system.

b) Partial PV-STATCOM mode: In this mode PV-STATCOM provides real power and the unused capability of the PV-System is utilised to provide reactive power to the grid.

c) Full STATCOM mode: This mode is used when there is any disturbance is the grid such as a fault. Solar inverter releases its capacity to supply reactive power and no active power is supplied.

4.2 Components of the System

The PV subsystem consists of photovoltaic panel array,coupling transformer, filter and inverter as shown in Figure 2.

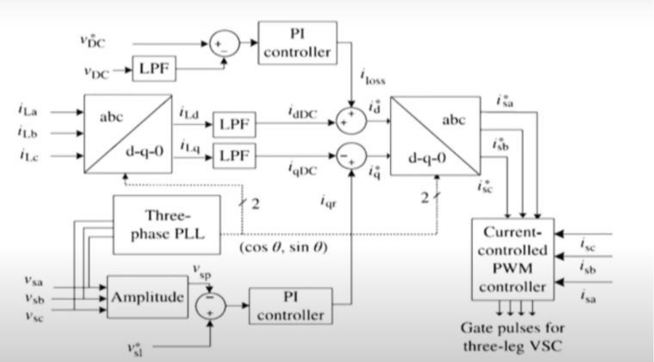

Figure 2: Block Diagram of SRF Theory Based Control Algorithm of PV-STATCOM

A comparison of the reference sources with the actual source currents (Isa; Isb; Isc) in the PCC generates the current error signal. Error signal so generated is used as a gate signal for generating PWM pulsed signals via the hysteresis PWM controller used for IGBT VSC switches.

5. DYNAMIC VOLTAGE RESTORER

A DVR's ultimate objective is to safeguard weak or weak loads against short-term tension drops and swells. Whenever a power line short circuits, On nearby feeders, a sudden voltage drop would be visible in the system network. The voltage of the line is restored to its normal level within a few milliseconds after a DVR is mounted on a load feeder.[29]

A DVR can be used to eliminate voltage slopes and swelling in order to improve power quality. DVR is a voltage compensator based on the inverter. DVR provides protection from voltage and power outages for precise manufacture processes and sophisticated, sensitive electronic equipment. DVR offers protection of subcycles, restores the quality of energy to the sensitive load. To restore the quality of power, DVR injects a three-phase voltages collection of acceptable amplitude and frequency in series with the supply voltage in synchronism via booster transformer.

Amplitude and angle of phase of the injection voltage are controllable. Reactive power exchange with out condenser or inducer between the DVR and the distribution system. The DVR is a series conditioner based on a voltage source inverter modulated with pulse width that independently generates or absorbs real or reactive power. The DVR is used to inject independent voltages into sensitive loads caused by faults. DVR provides highly regulated and clean output voltage[30]. The DVR provides harmonic compensation and reduces transient voltage.

SSSC and DVR, although, both devices are series connected, their location, Complexity, strategies of rating and control is overall different. An SSSC is mainly placed in the transmission system and increases the line's capacity for transmission. Normally, the rating in an SSSC is higher than in a DVR. It is more complicated than DVR to control SSSC. The distribution side is mainly integrated with a DVR. Compared to SSSC, it is less expensive. It can be used to alleviate many load side power quality issues. Control strategies are also quite straightforward.

For sensitive loads that are affected by fluctuations in system tension, the DVR is applicable. Power Quality issues cover a variety of perturbations, such as voltage drops, flickering, harmonic distortion, transient impulse, and interruptions.

The DVR is considered a successful custom unit because of its many advantages. It can manage the active energy flow. Costs of DVR are lower than those of others. Less maintenance is required and has higher capacity for energy. The size and cost of the DVR is lower compared to DSTATCOM, the voltage dip, the voltage swell, and other features, such as power factor correction and harmonics removal, can be added in the advantages provided by it.

Components of a DVR

The following are the key components of a dynamic voltage restorer [31]:

1) Boost/injection transformer: The power is converted to the secondary side with the aid of a booster transformer, which is often used to eliminate noise coupling.

2) Harmonic filter: The harmonic content provided by pulse width modulation is removed using a harmonic filter. Passive filters are used for this purpose.

3) Inverter: The inverter is utilised to transform dc voltage waveforms to ac voltage waveforms. A voltage source inverter is a power electronics device that generates sinusoidal voltage of any magnitude, frequency, or phase angle. It is made up of two parts: a power storage unit and a switching unit.

4) Energy storage device: This device is utilised to provide the power required for the generating injected voltage to the VSC through the DC connection.

5) Capacitor: A large-capacity capacitor is used in DVRs. It's often utilised to create a constant DC voltage for the inverter's input.

6) By-Pass Switch: If the load current reaches an acceptable value due to a large inrush current or a short circuit on the load, the DVR may be disconnected from the device by using bypass switches and providing a different current direction.

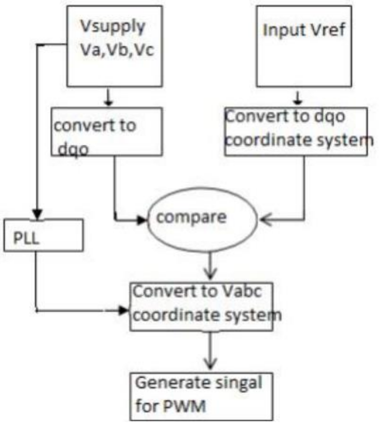

Figure 3: Flow Chart of Control Technique for DVR Based on DQO Transformation

The three phase voltages are translated to the stationary frame and then turned into a synchronous frame of reference. The synchronous reference value sag detector produces control signals to drive the PWM inverter to offset power sags. The synchronous voltages calculated are DC voltages. These voltages are constant in the normal condition. The difference between normal and sagging conditions of synchronous frame voltages generates switching pulse to the PW M inverter. Two signals, the wave and the control signal, control the switching of VSC's[37].

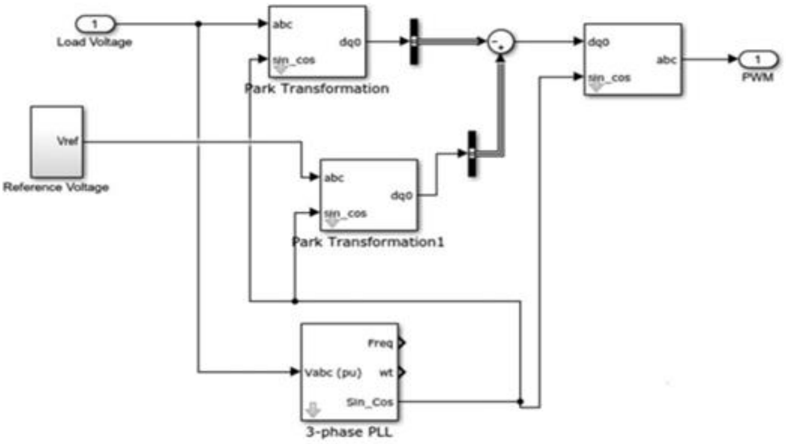

Figure 4: Schematic of Control Circuit for DVR

When the power systems' supply and load sides are not grounded, it is not necessary to offset the zero-sequence part of the load voltage. This results in cost-effective DVR as a reduction in the rating of the VSC and booster transformers is observed.

6. RESULTS ANALYSIS

6.1 PV-STATCOM

Simulink Model: In this work, simulation is performed in MATLAB, a Sim Power System was used to implement the PV-STATCOM model. The configuration of the system is shown by Figure 5.

Subsystems of PV-STATCOM are as follows:

1.The PV-STATCOM DC-link is linked to the DC DC boost conversion system.

2. To take the maximum PV power output from PV, the P&O MPPT controller is used.

3. PV-STATCOM-based VSC is connected in shunt with the load.

4. Load is non-linear and DC of 5kW.

5. After individual modelling, each specified component is simulated and integrated to the system.

Specifications of the system: Line voltage: 415V, Frequency=50Hz. SPV power output=100kW, Boost Converter Inductor = 1.73 mH, DC-link Capacitor = 61.43 μF, Filter Inductor = 500 μH, Filter capacitor= 100 μF. PWM Switching frequency of VSI = 10kHz, PWM Switching frequency of boost DC-DC Converter = 5kHz, Step Size Duty ratio of MPPT = 1V

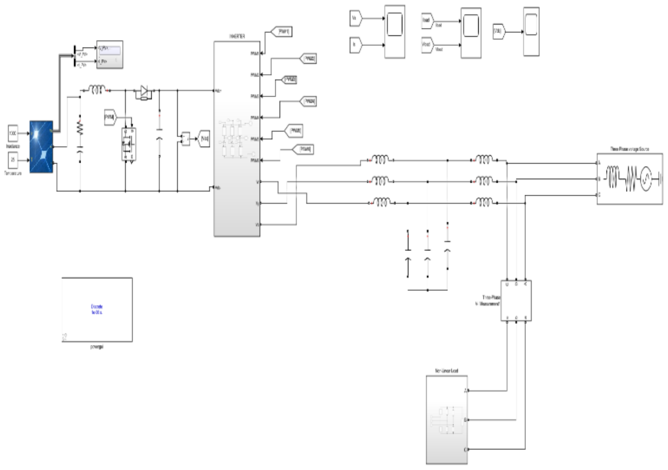

Figure 5:.Configuration of PV-DSTATCOM

Results: Analysis was conducted to improve the PQ of the grid when PV-STATCOM is integrated in the system. Figure 6 displays the DC-DC boost converter voltage waveform. Figure 7 show the phase voltage and current of load for PV-STATCOM. Figures 8 show that the load current becomes sinusoidal after PV-STATCOM is integrated and also provides an analysis of FFT for a PV-STATCOM load current. It illustrates that the system results using SPWM with PV-STATCOM reduces the THD content and improves the system's power quality. The THD of load current has been studied with PV-STATCOM. The load current THD of grid connected system with PV-STATCOM is 5.11%.

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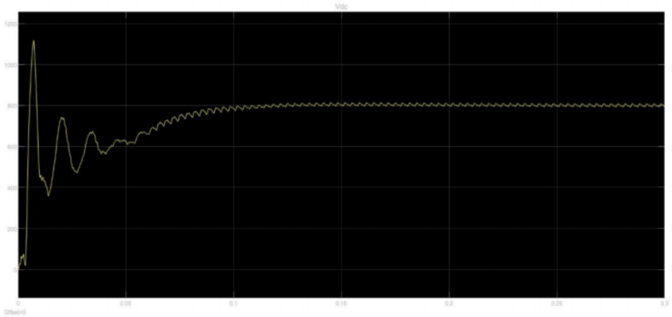

Figure 6: Waveform of DC-DC Boost Converter Voltage

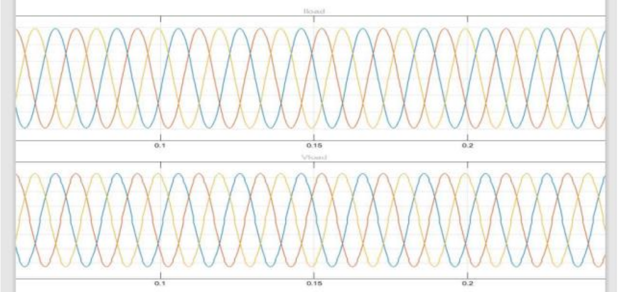

Figure 7: Load Current and Voltage with PV-STATCOM

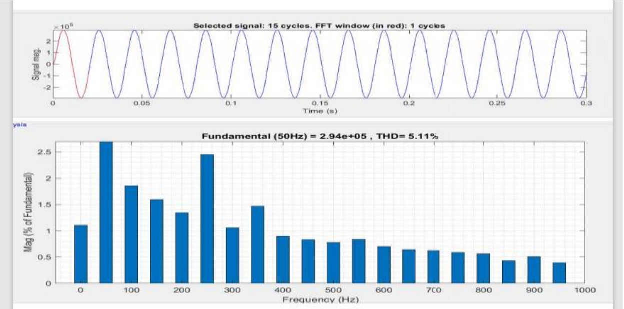

Figure 8: Analysis of FFT for Current at Load with PV-DSTATCOM

6.2 PV integrated Dynamic Voltage Restorer Simulink Model

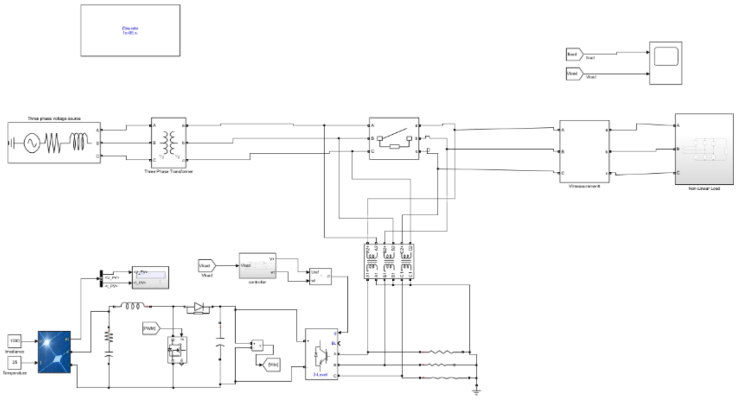

Figure 9: Configuration of PV integrated DVR

The system has been simulated in MATLAB SIMULINK, shown by Figure 9. With the 100kW solar photovoltaic array, a 25kV grid is incorporated via a DC-DC boost and a 3-leg source converter. The injection transformers link the

DVR in series with the system. DVR with a power circuit is simulated using the MATLAB/Simulink Platform with a modelling and structure of the power system and non-linear load control circuit.

Specifications of the system: Line voltage: 415V, Frequency=50Hz. SPV power output=100kW, Boost Converter Inductor = 1.73 mH, DC-link Capacitor = 61.43 μF, Filter Inductor = 500 μH, Filter capacitor= 100 μF. PWM Switching frequency of VSI = 10kHz, PWM Switching frequency of boost DC-DC Converter = 5kHz, Step Size Duty ratio of MPPT = 1V, Three phase transformer (12 terminals) = 1.5kVA, Three Phase Transformer = 30MVA

Results: DVR has proved to be a useful and efficient device and the most notable tool for enhancing the quality of power. Analysis was conducted to improve the PQ of the grid when solar PV and DVR is integrated in the system. Figures 10 show the phase voltage and current of load with DVR connected in parallel .Figures 11 provides an analysis of FFT for a DVR load current and show that the load current becomes sinusoidal after DVR is integrated. It illustrates that the system results using DVR in shunt with load reduces the THD content and improves the system's power quality. The THD of load current has been studied with DVR. The load current THD of grid connected system with DVR is 3.07%.

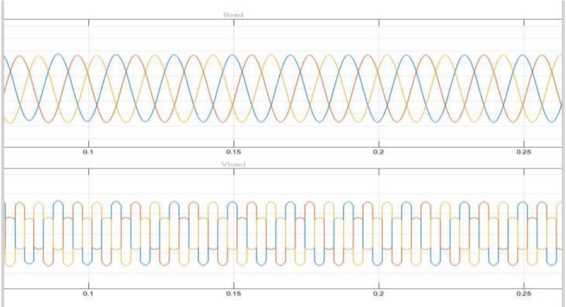

Figure 10 Load Current and Voltage with PV Integrated DVR

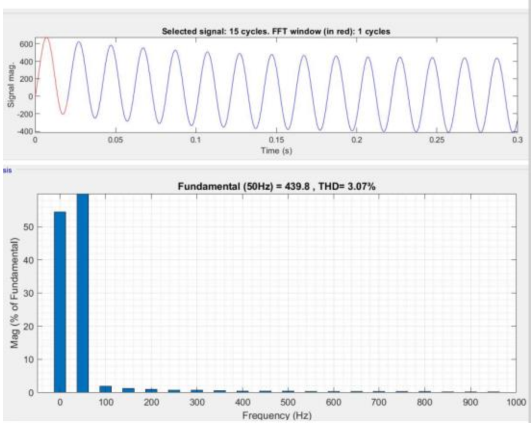

Figure 11 Analysis of FFT for Current at Load with PV Integrated DVR

7. CONCLUSIONS AND FUTURE WORK

Conclusion

This work has presented mitigation of the power quality problems by integrating PV-system with DVR and D-STATCOM. The model of PV integrated DVR and D-STATCOM and comprehensive results in mitigating PQ issues have been presented..

The comparison between D-STATCOM and DVR has been performed by using MATLAB/SIMULINK software. The THD analysis for three cases has been done.

Case1: When compensating devices and PV are not integrated in the system. The THD of load current obtained was 27.41%.

Case2: When PV-STATCOM is connected in shunt with the load. The load current THD is found to be 5.11%.

Case3: When PV integrated DVR is connected in series with the load. The load current THD is found to be 3.07 %.

The result obtained from the simulation clearly shows that the DVR provides relatively better PQ mitigation results. By considering the results obtained from this project work finally we can conclude that DVR shows the better efficiency and effectiveness in mitigating PQ issues as compared to PV-Statcom. The objective of the project has been achieved. The simulation results presented shows good accuracy with results.

Future Work

Harmonic removal, load balancing, voltage control, and power factor correction are the PQ challenges that the DSTATCOM and DVR can help with. However, the current cost of DSTATCOM is on the higher end of the scale which is the major obstacle to its deployment in the system. As a result, conducting significant research is extremely desired to decrease the cost of DSTATCOM without sacrificing effectiveness and efficiency to increase PQ.

This dissertation focuses on the PV-DSTATCOM and PV-DVR system, which employs various topologies and control methodologies to handle PQ problems like current harmonics and reactive power. Because today's distribution system necessitates PV-UPQC, which combines PVDSTATCOM and PV-DVR to improve the quality of voltage provided and current drawn, has a lot of potential in real-world applications. Therefore , applying the control strategies for PV-UPQC is an appropriate extension of the thesis work.

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