

Compensating Voltage SAG/SWELL, THD using IDVR and STATCOM on integration of wind energy system into Distribution Network

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Abstract: Power electronics converter based dynamic voltage restorer (DVR) has been used for compensation or mitigation of sudden rise/dips in voltage level under the usage of sensitive loads. To reduce total harmonic distortion (THD) different FACTS devices are used in distribution system side mainly for fluctuating renewable energy sources like wind, solar, etc. This paper proposes a new device namely interline dynamic voltage restorer (IDVR) with a common DC link with simple pulse width modulation (PWM) control. And also FACTS device STATCOM has been added in this network to reduce the total harmonic distortion (THD) mainly for wind energy system when connected to the grid side distribution system. To compensate these power quality issues the measurements and norms are followed according to guidelines given in International Electrotechnical Commission (IEC - 61400) standard, thereby the performance of the wind energy system and power quality issues are determined under sensitive loads. This IDVR and STATCOM with a wind energy system have been simulated and analyzed the results using MATLAB/Simulink. The voltage Sag/swell and THD are compensated on distribution side network. The performance of the network also studied and analyzed what happens when the energy stored in common dc link discharges suddenly with the simulated results.

Key words: Interline dynamic voltage restorer, Static compensator (STATCOM), Voltage sag/swell, total harmonic distortion (THD), Wind energy system, Pulse width modulation (PWM).

1 Introduction:

Due to fast growth of population in the world, need of electrical energy for various utilities are keep on increasing. Various types of power generation are there, but there is no way to reduce the usage of power. Only way is to increase the production from various available sources like renewable, non-renewable energy sources. Problem with the non-renewable energy sources is that less availability, not constant with climate, sometimes unavailability. If we are considering solar energy based power production, solar radiation availability is there only during day time in night time or peak time we can't produce energy and also in rainy season. The integration of wind energy system into existing power system network presents technical challenges and that forces consideration of voltage variations, stability, harmonic problems. The power quality is an essential consumer-focused measure and is very much affected by the operation of a distribution and transmission system network.

In this world there are three different categories of nations which are developed, developing and under developing. Peoples in these three nations, mostly everyone using advanced and hands on technologies for their everyday work progress in which major equipment's or utilities are developed with the electronics and power electronics based technology. All the power electronic based utilities are very sensitivity in nature because of its switching condition; due to this most of the harmonics are generated. During unbalanced, sudden increase in load power quality issues like voltage distortions, sag/swell will arise due to this utility equipment's may get damaged, so some external devices has to be used to compensate the issues. The voltage source inverter based dynamic voltage restorer is connected with three phase transmission line to compensate the variations in voltage like voltage sag/swell by injecting three phase voltage into the transmission line [1].

The magnitude and phase angles of the injected three-phase voltage can be varied, thereby allowing control of real power and reactive power exchanged between the DVR and the distribution system. The amount of real power and reactive power provided by the DVR depends on the type of voltage disturbance occurred due to load variations, the power requirements of the protected load and the direction and magnitude of the injected three phase voltage [2]. The mitigation of the voltage sag/swell is mainly depends on device connected in series with the line and the energy storage to supply when DVR comes in to operation. DVR is compensating the voltage sag even for long duration very effectively, but it requires appropriate energy capacity. The magnitude and phase angle of injected three phase voltage are variables which result in variable real and reactive power exchange between the DVR and transmission line to supply the sensitive load or the distribution system network [3].

The progressive phase advance technique where all the three-phase voltages are progressively advanced by a certain angle α to reduce the amount of real power supplied by the DVR has been mentioned in these papers. In this paper we propose a concept of IDVR or MDVR, which is connecting number of DVR's in a common DC link. This concept is basically based on the interline power flow controller (IPFC) where connecting number of inverters

connecting in common DC link for effective power flow management. [4,5]

The injected three phase voltage of the DVR depends on the accuracy and dynamic behaviour of the pulse width modulated (PWM) voltage synthesis scheme and control system used. This paper also presents an extensive analysis to develop suitable control schemes for voltage sag compensation and THD minimization. The general requirement of such control scheme is to obtain an ac waveform with low total harmonic distortion (THD) it can be minimized using STATCOM and good dynamic response against supply and load disturbance whether the DVR in IDVR system operates in voltage compensation control mode. Usually the control voltage of the DVR in mitigating voltage sag/swell is derived by comparing the supply voltage against a reference waveform. In this paper a shunt connected FACTS device called STATCOM is also used to minimize the THD generated due to electronic loads. STATCOM is used because of its simplicity, low cost, effective reactive power compensation. Reactive power compensation is mainly for the grid connected wind energy system. And also analyzing the common DC link energy storage capacity [6, 7]

2 Basic Operational Principles of DVR, IDVR and STATCOM

2.1 DVR – Dynamic Voltage Restorer

The dynamic voltage restorer is a series connected device, which by voltage injection can control the load voltage. In the case of a voltage dip the DVR injects the missing voltage and it avoids any tripping the load. Fig. 1 shows the operation principle of a DVR. The DVR considered consists of:

- an injection / series transformer
- a harmonic filter,
- a Voltage Source Converter (VSC),
- an energy storage and
- a control system , as shown in Figure 1

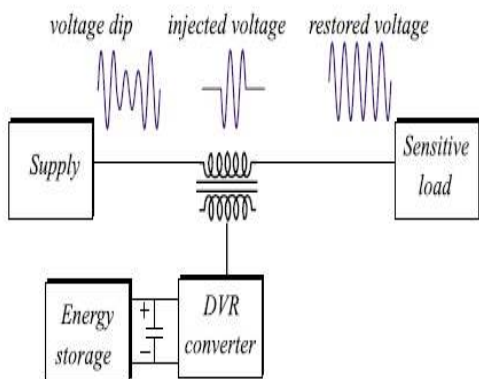


Fig.1. Operation Principle of DVR

Dynamic Voltage Restorer is a distribution voltage DC-to-AC solid-state switching inverter that injects three phase AC output voltages in series with the distribution feeder and in synchronicity with the voltages of the distribution system network using series injection transformer. By injecting three phase AC voltages of controllable amplitude, phase angle, and frequency (harmonic THD) into the distribution feeder in instantaneous real time via a series injection transformer, the DVR can restore the quality of three phase AC voltage at its load side terminals when the quality of the source side terminal voltage is distorted (sag/swell) due to sensitive loads. [8, 9]

2.2 IDVR – Interline Dynamic Voltage Restorer

The IDVR system consists of two or more DVRs protecting sensitive loads in different distribution system feeders emanating from different grid substations network, and these DVRs share a common DC link. The interline power flow controller scheme provides a capability to transfer real power directly between the two compensated lines, while the reactive power is controllable within each individual transmission line. The IDVR system consists of two or more DVRs in different feeders, sharing a common dc link.

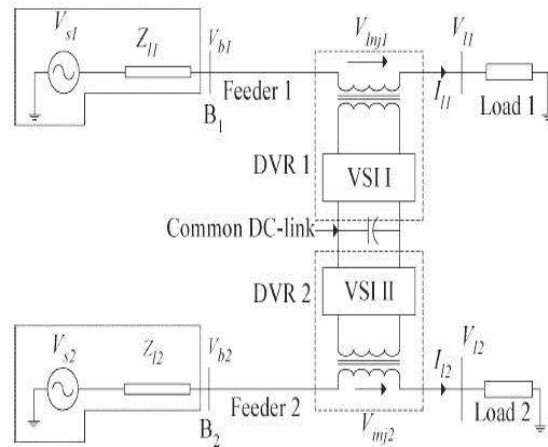


Fig.2. IDVR

A two-line IDVR system shown in Fig. 2 employs two DVRs connected to two different distribution network feeders originating from two grid substations. These two feeders could be of the same voltage magnitude or different voltage magnitude level. When one of the DVRs or sometimes two DVR compensates for voltage sag, if only one DVR compensates sag then the other DVR in IDVR system operates in power-flow control mode to replenish dc link energy storage which is depleted due to the real power taken by the DVR working in the voltage-sag compensation mode. Propagation of voltage sag/swell due to fault in the power system depends on many

factors, such as voltage magnitude level, fault current, transformer in the propagation path line and their connection arrangement, etc. Voltage sags in a transmission system are likely to propagate to long duration or short duration depends on the fault occurred in a distribution system. Due to these factors and as the two feeders of the IDVR (DVR 1 and DVR2) system in Fig. 2 are connected to two different grid substations network, it is reasonable to assume that the voltage sag in Feeder 1 would have a lesser impact on Feeder 2. Therefore, the upstream generation-transmission system to the two feeders can be considered as two independent three phase sources. [10]

2.3 STATCOM – Static Compensator

The STATCOM (or SC) is a shunt-connected reactive-power compensation device (FACTS Device) that is capable of generating and/ or absorbing reactive power and in which the output voltage can be varied to control the specific parameters of an electric power system. The STATCOM basic diagram is shown in Fig.3. It is in general a power electronics based solid-state switching converter capable of generating or absorbing independently controllable real and reactive power at its output terminals when it is fed from an energy source or energy-storage device (battery) at its input terminals. The dc voltage is provided by an energy-storage capacitor.

A STATCOM can improve power-system performance in such areas as the following:

1. The dynamic voltage control of transmission and distribution network systems;
2. The power-oscillation damping in power-transmission network systems;
3. The transient stability control;
4. The voltage variation control; and
5. The control of not only reactive power but also (if needed) real power in the connected transmission line, requiring a dc energy source.

Furthermore, a STATCOM does the following:

1. It occupies a small footprint, for it replaces passive banks of control circuit elements by compact power electronic converters;
2. It offers modular, factory-built equipment, thereby reducing site work and installation time; and
3. It uses encapsulated power electronic converters, thereby minimizing its environmental impact.

A STATCOM is analogous to an ideal synchronous machine, which generates a balanced set of three phase sinusoidal voltages at the fundamental frequency with controllable magnitude and phase angle. This ideal machine has no inertia, is practically instantaneous, does not significantly alter the existing system impedance, and can internally generate reactive (both capacitive and inductive) power. [7]

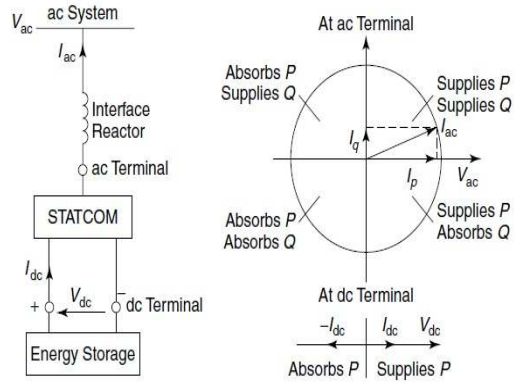


Fig.3. Static Compensator

3 Power Quality Issues, Consequences and Standards

Power distribution systems, ideally, should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency. However, in practice, power systems, especially the distribution systems, have numerous nonlinear loads, which significantly affect the quality of power supplies. As a result of the nonlinear loads, the purity of the waveform of supplies is lost. This ends up producing many power quality problems. While power disturbances occur on all electrical systems, the sensitivity of today's sophisticated electronic devices makes them more susceptible to the quality of power supply. For some sensitive devices, a momentary disturbance can cause scrambled data, interrupted communications, a frozen mouse, system crashes and equipment failure etc. A power voltage spike can damage valuable components. Power Quality problems encompass a wide range of disturbances such as voltage sags/swells, flicker, harmonics distortion, impulse transient, and interruptions. [7]

3.1 Voltage sag

Voltage sags can occur at any instant of time, with amplitudes ranging from 10 – 90% and a duration lasting for half a cycle to one minute. The voltage sag is due to startup of wind turbine and it causes a sudden reduction of voltage. It is the relative % voltage change due to switching operation of wind turbine. The decrease of nominal voltage change is given in Eq. 1.

$$\Delta d = L_u \frac{P_n}{P_k} \quad (1)$$

Where Δd is relative voltage change, P_n is rated apparent power, P_k is short circuit apparent power, and L_u is sudden voltage reduction factor. The acceptable voltage dips limiting value is $< 3\%$.

3.2 Voltage swell

Voltage swell is defined as an increase in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 min. The voltage swell at the point of common coupling can be approximated as a function of maximum apparent power P_{max} of the turbine, the grid impedances R and X at the point of common coupling and the phase angle ϕ , given in Eq. 2. [11]

$$\Delta v = \frac{P_{max}(R \cos \phi - X \sin \phi)}{V^2} \quad (2)$$

Where Δv —voltage rise, P_{max} —max. apparent power, ϕ —phase difference, v —nominal voltage of grid. The Limiting voltage rise value is <2 %

3.3 Harmonics

The total harmonic distortion results due to the operation of power electronic converters. The harmonic voltage and current should be limited to the acceptable level at the point of wind energy system connection to the network. To ensure the harmonic voltage within limit, each source of harmonic current can allow only a limited contribution to the network, as per the IEC-61400-36 standard guideline. The rapid switching gives a large reduction in lower order harmonic current compared to the line commutated converter, but the output current will have high frequency current and can be easily filter-out.

3.4 IEC Guidelines

The IEC provided some guidelines for measurement of power quality of wind turbine. The International standards are developed by the working group of Technical Committee-88 of the International Electrotechnical Commission (IEC), IEC standard 61400-21, describes the procedure for determining the power quality characteristics of the wind turbine. [12]

The standard norms are specified. 1) IEC 61400-21: Wind turbine generating system, part-21. Measurement and Assessment of power quality characteristic of grid connected wind turbine. 2) IEC 61400-13: Wind Turbine—measuring procedure in determining the power behavior. 3) IEC 61400-3-7: Assessment of emission limits for fluctuating load IEC 61400-12: Wind Turbine performance. The data sheet with electrical characteristic of wind turbine provides the base for the utility assessment regarding a grid connection.

4 Proposed IDVR method and Control System Algorithm

In the proposed method, considering two DVRs connected with a common DC link connected to two different transmission line which is shown in fig 4 for

the compensation of voltage sag/swell when the wind energy system is connected to the distribution side grid network. From Fig. 4 it shows that two wind energy system is connected directly to the two different distribution network for separate energy consumption. In most of the cases from IDVR either DVR 1 or DVR 2 will be used for the voltage sag compensation and either or DVRs will be used for the real power supply to the common DC link for the another DVR to compensate the voltage sag. But in our proposed IDVR network model we considering both the DVRs (DVR1 and DVR 2) for voltage sag compensation with the high rated DC link capacitors.

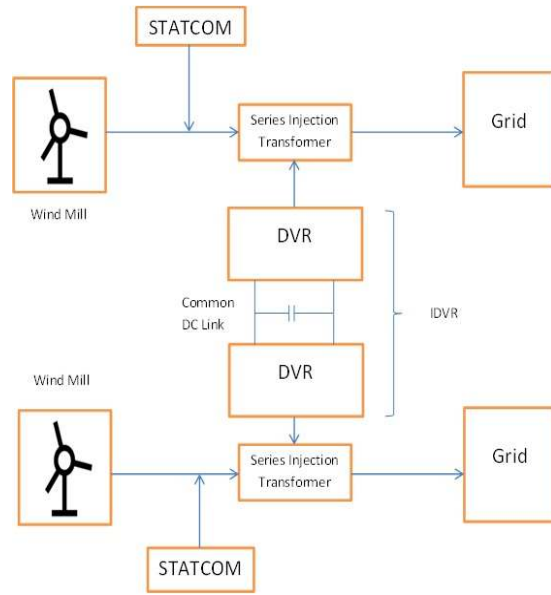


Fig.4. Proposed IDVR model with Wind mill and STATCOM

The proposed IDVR and STATCOM model is not only used for voltage sag compensation but also for voltage swell compensation and THD reduction. With this IDVR model we considered voltage sag for one network and voltage swell for another network and also we considered for voltage sag in two networks and voltage swell in two networks same time. For the control of two DVRs we used simple PWM control scheme separately for different DVRs which combined gives IDVR system.

4.1 Control System Algorithm (PWM)

The basic functions of a controller in an IDVR (DVR1, DVR2) are the detection of voltage sag/swell events in the distribution system; computation of the correcting voltage, generation of trigger pulses to the sinusoidal PWM based DC-AC inverter, correction of any anomalies in the series voltage injection through

series transformer and termination of the trigger pulses when the sag/swell event has passed. The PWM controller may also be used to shift the DC-AC inverter into rectifier mode to charge the capacitors in the DC energy link in the absence of voltage sags/swells.

The dqo transformation or Park's transformation is used to control two DVRs. The dqo method gives the sag depth and phase shift information with sag start and sag end times. The quantities are expressed as the instantaneous space vectors. Firstly convert the voltage from abc reference frame to d-q-o reference. For simplicity zero phase sequence components is ignored. Figure 5 shows the flow chart of the feed forward dqo transformation for voltage sags/swells detection. The detection is carried out in each of the three phases for two different distribution network. [13, 14]

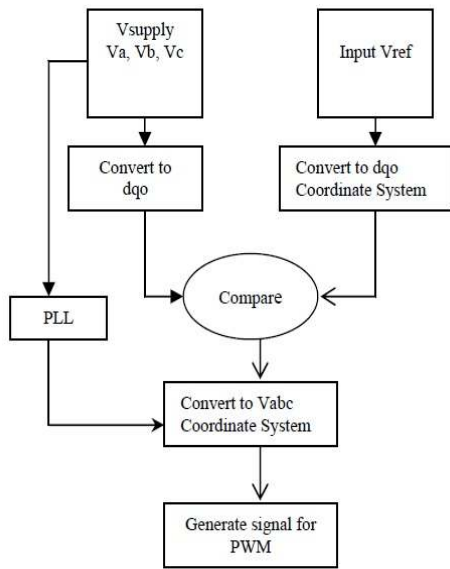


Fig.5. Flow Chart

The PWM control scheme for the proposed system is based on the comparison of a voltage reference and the measured terminal voltage (Va,Vb,Vc).The voltage sags is detected when the input supply voltage from wind mill drops below 90% of the reference value whereas voltage swells is detected when the input supply voltage from wind mill increases up to 20% of the reference value. The error signal is used as a modulation signal that allows generating a commutation pattern of PWM signals for the power electronic switches (IGBT's) constituting the voltage source converter. The commutation pattern is generated by means of the pulse width modulation technique (PWM); voltages are controlled through the modulation signal generated due to error. The block diagram of the phase locked loop (PLL) is illustrated in Figure 5. The PLL circuit is used to generate a unit sinusoidal wave signal in phase with mains voltage.

5 Proposed Model Simulation Results and Discussion

The proposed IDVR system has been simulated using MATLAB/Simulink and various analysis have been made. The various analysis are sag in both network, swell in both network, THD analysis for SAGSWELL, combined sag/swell and variations in DC link capacitor on operation of single and two network. The results are analyzed below as follows.

5.1 Voltage Sag Results of Proposed System

Long duration voltage sag has been made for analysis with the three phase network where the wind energy system is delivering power with lot of variation in voltage level. But the variation is first compensated using STATCOM and the long duration say about 0.2 seconds from 0.15 sec to 0.35 sec has created, then the voltage sag is compensated on both the networks using IDVR with a PWM control. Output voltage and input voltages are same. The result is shown in fig. 6 it contains input, injected, output voltages and error signal.



Fig.6. Voltage SAG for 0.2 sec

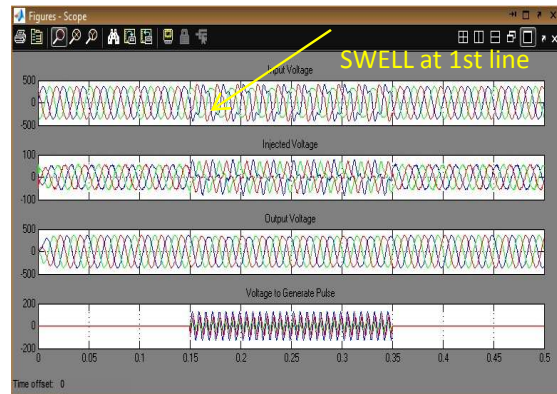


Fig.7. Voltage SWELL for 0.2 sec

5.2 Voltage Swell Results of Proposed System

Long duration voltage swell has been made for analysis with the three phase network where the wind energy system is delivering power with lot of variation in voltage level. But the variation is first compensated using STATCOM and the long duration say about 0.2 seconds from 0.15 sec to 0.35 sec has created, then the voltage swell is compensated on both the networks using IDVR with a PWM control. Output voltage and input voltages are same. The result is shown in fig. 7 it contains input, injected, output voltages and error signal.

5.3 THD Analysis for SAG and SWELL

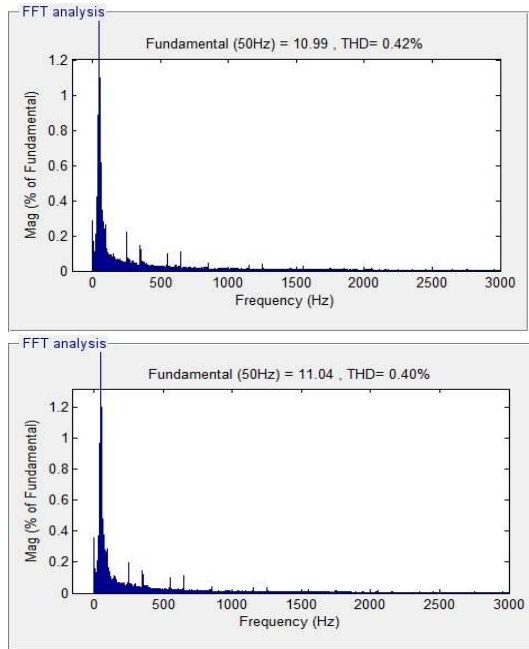


Fig. 8. THD analysis with Wind energy system

By integrating Wind energy system into the distribution network there is not only voltage sag and swell, and also severe harmonic problem will arise so we used STATCOM to minimize the THD. The minimized THD value is acceptable according to the IEC guidelines. The minimized THD value when SAG is created is 0.42% and when SWELL is created the minimized THD value is 0.40% it shows that STATCOM has given his part for compensation. Fig. 8. Shows the THD results.

5.4 DC link Capacitor Problem

The DC link capacitor plays the important role for the operation of IDVR. It supplies the energy whenever a SAG or SWELL occurs in the distribution network. We have considered and analyzed what happens when DC link Capacitor fails or gets discharged quickly while the IDVR is in operation. So that we analyzed

with various ratings of capacitor values and founded that large capacitor is requires for the long duration voltage SAG and SWELL compensation. From this we concluded that the DC link capacitor fails there is a no compensation for both SAG and SWELL. The table below shows the analysis of capacitor values for DVR, IDVR with single line operation and IDVR with two line operation. The timing shows the operation of IDVR until the capacitor gets discharged, where IDVR with one line operation takes more time to get discharged.

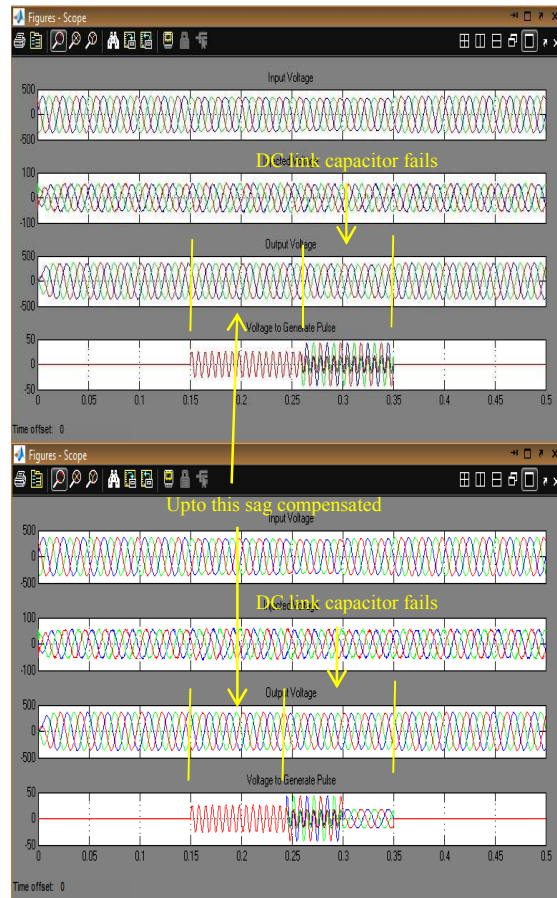


Fig. 9. Affected Voltage SAG control due to failure of DC link capacitor

Table 1. Analysis of DC link capacitor with DVR and IDVR

Total Voltage SAG Length is 0.2 seconds				
s.no	Capacitor Value	DVR	IDVR with 1 Transmission Line	IDVR with 2 Transmission Line
1	100 nF	0.03 sec	0.05 sec	0.04 sec
2	1000 μ F	0.07 sec	0.09 sec	0.075 sec
3	100 μ F	0.09 sec	0.11 sec	0.095 sec
4	1 μ F	0.12 sec	0.15 sec	0.13 sec

5	0.01 μ F	0.15 sec	0.175 sec	0.17 sec
6	0.00001 μ F	0.2 sec	0.2 sec	0.2 sec

6 Conclusion

In this paper we proposed an IDVR control scheme for voltage SAG and voltage SWELL compensation when wind energy system is integrated with the distribution system network with STATCOM for THD minimization also. We connected wind energy system with the distribution network to get utilize the generated power. The harmonic problem arises with the variation in the wind with that it produces variable power output, so the variation in voltage is controlled and THD is minimized by connecting the shunt device called STATCOM.

The created long duration voltage SAG and voltage SWELL has been compensated using IDVR device. The IDVR device is controlled by PWM control method for simplicity, where the PWM control method generates pulses for inverter is based on error signal generated on comparison of reference and measured signal. The proposed method is studied and analyzed with various focus like compensating both the lines at same time, different time, SAG on both lines, SWELL on both lines, SAG in one line and SWELL in another line and main analysis made in this paper is that the problem with the DC link capacitor and problem with wind variation.

The DC link capacitor is analyzed with various capacitors values and with different devices along with creating SAG in only one distribution line. All the results are shown in various figures and the DC link capacitor analysis is tabulated.

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