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MITIGATION OF POWER QUALITY PROBLEMS USING SOLAR ENERGY-BASED THREE-PHASE DVR WITH FUZZY LOGIC CONTROLLED NOVEL BOOST INVERTER

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ABSTRACT

Voltage sags result in unwanted operation stops and large economic losses in industrial applications. A dynamic voltage restorer (DVR) is a power-electronics-based device conceived to protect high-power installations against these events. However, the design of a DVR control system is not straightforward and it has some peculiarities. First of all, a DVR includes a resonant (LC) connection filter with a lightly damped resonance. Secondly, the control system of a DVR should work properly regardless of the type of load, which can be linear or non-linear, to be protected. In order to improve the utilization rate and power quality of distributed new energy power generation technology and, to solve the voltage fluctuation problem in the operation of the Distributed photovoltaic storage and grid-connected system. This project proposes a control strategy based on DVR (dynamic voltage restorer) for operation of distributed photovoltaic storage and grid-connected. The remaining photovoltaic output energy is stored in energy storage via active bridge to reduce the waste of photovoltaic power.

To compensate the output voltage fluctuation of photovoltaic grid-connected inverter, the DVR was connected to the energy storage. And PI controller parameters of the DVR are optimized by ANFIS algorithm, realize the recovery of output voltage fluctuation of the photovoltaic grid-connected inverter. The advantages of the proposed control strategy are demonstrated using simulations, and the results show that the proposed strategy can ensure the quality of PV output voltage in the photovoltaic storage and grid connected. PV based DVR system is comprised of PV System with low and high power DC-DC boost converter, PWM voltage source inverter, series injection transformer and semiconductor switches. Simulation results proved the capability of the proposed DVR in mitigating the voltage sag, swell and outage in a low voltage distribution system.

KEYWORDS: *New Energy Power Generation Technology*

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INTRODUCTION

Most downtimes in industry are due to voltage sags. Unfortunately, it is difficult to immunize equipment against these voltage events and, if the sag lasts for a long time, equipment shutdown is inevitable. Uninterruptible power supplies (UPSs) are often used for protecting sensitive loads against voltage sags. UPSs are widely applied to protect low-power loads such as computers or small electronic loads. They replace the grid when a voltage sag takes place and, when the voltage level recovers, loads are gently reconnected to the grid. However, a UPS has to deliver all the power consumed by the protected loads during a sag. This means that a UPS requires large batteries to protect loads against long-duration voltage sags and, consequently, its application is greatly restricted by the size and cost of batteries. A dynamic voltage restorer (DVR) is conceived to protect sensitive loads. against voltage sags and swells.

This device is connected in series with an electrical distribution line and, typically, it consists of a voltage source converter (VSC), a DC capacitor, a coupling transformer, batteries, and an AC filter. When voltage sag takes place, a DVR injects the required voltage in series with the feeding line and the load voltage remains unchanged. The main advantage of DVRs is that only a portion of the power consumed by the load is supplied from the batteries. This means that batteries can be made much smaller than in a typical UPS and cost can be reduced. These reductions in battery size and cost make DVRs very attractive for high-power applications where a UPS may be infeasible. A series-connected power-electronics device that was able to restore the voltage of a load under distorted grid conditions. AC–DC converter was used to maintain the DC voltage constant so that no additional energy storage elements were required. The main task of a DVR is to control the load voltage. Therefore, a control scheme is commonly adopted. DVRs are sometimes controlled by using open-loop techniques. Stability is guaranteed with this control technique if the plant is stable (alwaysthe case for a DVR).

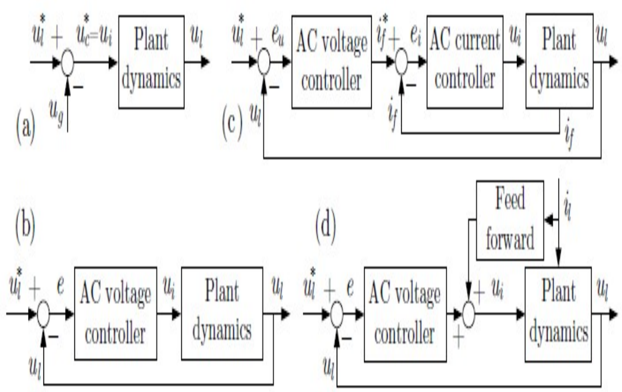

Figure 1: Most Relevant Dynamic Voltage Restorer (DVR) Control Strategies: (a) Open-Loop Control, (b) Single-Loop Control, (c) Multi-Loop Control, and (d) Single-Loop Control with Current Feed-Forward.

However, the system performance deteriorates when there are disturbances. Open-loop control has clear drawbacks:

- Accurate reference tracking is only possible if the plant model is exactly known.
- Disturbances cannot be rejected.
- It is almost impossible to track voltage harmonics.

CONTROL TECHNIQUES

Open-loop control techniques were applied to control a DVR, obtaining a fast transient response. However, performance was poor if the AC filter included a capacitor because of the LC filter resonance. In most cases, DVRs are controlled by using a feedback control scheme. Additionally, the current consumed by the sensitive load can be added as a feed-forward signal. Feedback control provides accurate reference tracking provided the closed-loop plant is stable.

However, DVR feedback control can be difficult because

- The load modifies the plant dynamics and
- The LC filter resonance is difficult to damp with a controller based on a single loop.

If the controller is applied in natural magnitudes or in a stationary RF (*ab*), decoupling equations are not required. However, a resonant controller is needed to achieve zero steady-state error for the fundamental component. By far, the most common alternative is to use an SRF because the fundamental components of all magnitudes are constant values in steady state. Therefore, a proportional-integral (PI) controller is enough to track balanced voltage sags, although the dq-axis dynamics are coupled.

In addition, a phase-locked loop (PLL) is needed to synchronize with the grid voltage. An alternative controller was implemented by using time-varying phasors that did not require a PLL and made it possible to independently control each phase. However, the transient response was slower when compared to other control algorithms because the phasors needed to be estimated. The simplest solution to damp the resonance is to add a resistor close to the AC capacitor, but this increases losses. A multi-loop control scheme like the one depicted in Figure 1c is a classical solution to damp resonances: first, the current through the filter inductor (il) is controlled by the inner AC-current controller, and, secondly, the load voltage (ul) is controlled by the AC-voltage controller. With this control scheme, the resonance can be actively damped and no extra passive elements are required.

Nevertheless, extra measurements are required. A DVR can also be controlled by using a single control loop. For instance controlled a DVR with an LC filter by applying a PID controller and a fast transient response with a reduced overshoot was obtained. However, the load voltage quality deteriorated when loads were non-linear. Alternatively, Roncero-Sánchez et al. damped the resonance by applying a PI controller plus a notch filter tuned at the resonant frequency: the notch filter simplified the PI controller design, but the result was not robust against variations in the system parameters.

POWER QUALITY PROBLEMS

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 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 produce 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.

- Voltage dip: A voltage dip is used to refer to short-term reduction in voltage of less than half a second.
- 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.

- 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.
- Voltage 'spikes', 'impulses' or 'surges': These are terms used to describe abrupt, very brief increases in voltage value.
- Voltage transients: They are temporary, undesirable voltages that appear on the power supply line. Transients are high over-voltage disturbances (up to 20KV) that last for a very short time.
- Harmonics: The fundamental frequency of the AC electric power distribution system is 50 Hz. A harmonic frequency is any sinusoidal frequency, which is a multiple of the fundamental frequency. Harmonic frequencies can be even or odd multiples of the sinusoidal fundamental frequency.
- Flickers: Visual irritation and introduction of many harmonic components in the supply power and their associated ill effects.

Causes of Dips, Sags and Surges:

- Rural location remote from power source
- Unbalanced load on a three phase system
- Switching of heavy loads
- Long distance from a distribution transformer with interposed loads
- Unreliable grid systems
- Equipments not suitable for local supply

ENERGY STORAGE SYSTEMS

Storage systems can be used to protect sensitive production equipments from shutdowns caused by voltage sags or momentary interruptions. These are usually DC storage systems such as UPS, batteries, superconducting magnet energy storage (SMES), storage capacitors or even fly wheels driving DC generators .The output of these devices can be supplied to the system through an inverter on a momentary basis by a fast acting electronic switch. Enough energy is fed to the system to compensate for the energy that would be lost by the voltage sag or interruption. Though there are many different methods to mitigate voltage sags and swells, but the use of a custom Power device is considered to be the most efficient method. For example, Flexible AC Transmission Systems (FACTS) for transmission systems, the term custom power pertains to the use of power electronics controllers in a distribution system, specially, to deal with various power quality problems. Just as FACTS improves the power transfer capabilities and stability margins, custom power makes sure customers get pre-specified quality and reliability of supply. This pre-specified quality may contain a combination of specifications of the following:

- Low phase unbalance, no power interruptions, low flicker at the load voltage, low harmonic distortion in load voltage, magnitude and duration of overvoltage and under voltages within specified limits, acceptance of fluctuations, and poor factor loads without significant effect on the terminal voltage There are many types of Custom Power devices.

Some of these devices include:

- Active Power Filters (APF), Battery Energy Storage Systems (BESS), Distribution STATic synchronous COMpensators (DSTATCOM), Distribution Series Capacitors (DSC), Dynamic Voltage Restorer (DVR), Surge Arresters (SA), Super conducting Magnetic Energy Systems (SMES),
- Static Electronic Tap Changers (SETC), Solid-State Transfer Switches (SSTS), Solid State Fault Current Limiter (SSFCL), Static Var Compensator (SVC), Thyristor Switched Capacitors (TSC), and Uninterruptible Power Supplies (UPS).

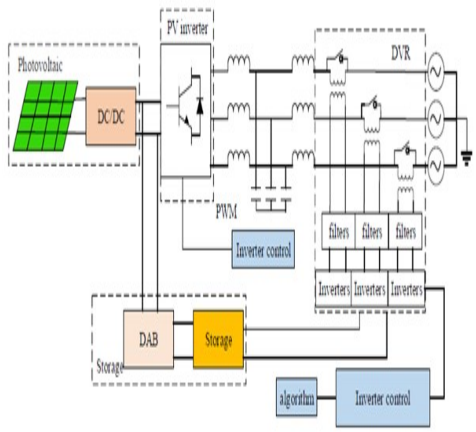

Figure 2: Photovoltaic Energy Storage and Grid Connected System Structure.

MPPT CONTROL TECHNIQUE

Maximum power point tracing (MPPT) system is an electronic control system that can be able to coerce the maximum power from a PV system. It does not involve a single mechanical component that results in the movement of the modules changing their direction and make them face straight towards the sun. MPPT control system is a completely electronic system which can deliver maximum allowable power by varying the operating point of the modules electrically.

NECESSITY OF MAXIMUM POWER POINT TRACKING

In the Power Vs Voltage characteristic of a PV module shown in fig 2.8 we can observe that there exist single maxima i.e. a maximum power point associated with a specific voltage and current that are supplied. The overall efficiency of a module is very low around 12%. So it is necessary to conditions. This increased power makes it better for the use of the solar PV module. A DC/DC converter which is placed next to the PV module extracts maximum power by matching the impedance of the circuit to the impedance of the PV module and transfers it to the load. Impedance matching can be done by varying the duty cycle of the switching elements. MPPT algorithm There are many algorithms which help in tracing the maximum power point of the PV module. They are following: a. P&O algorithm b. IC algorithm c. Parasitic capacitance d. Voltage based peak power tracking e. Current Based peak power tracking Perturb and observe Each and every MPPT algorithm has its own advantages and disadvantages. Perturb and observe (P&O) method is widely used due its simplicity. In this algorithm we introduce a perturbation in the operating voltage of the panel. Perturbation in voltage can be done by altering the value of duty-cycle of dc-dc converter operate it at the crest power point so that the maximum power can be provided to the load irrespective of continuously changing environmental.

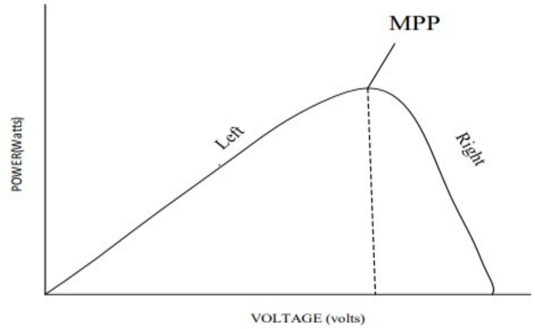

Figure 3: P-V Characteristics (basic idea of P&O algorithm).

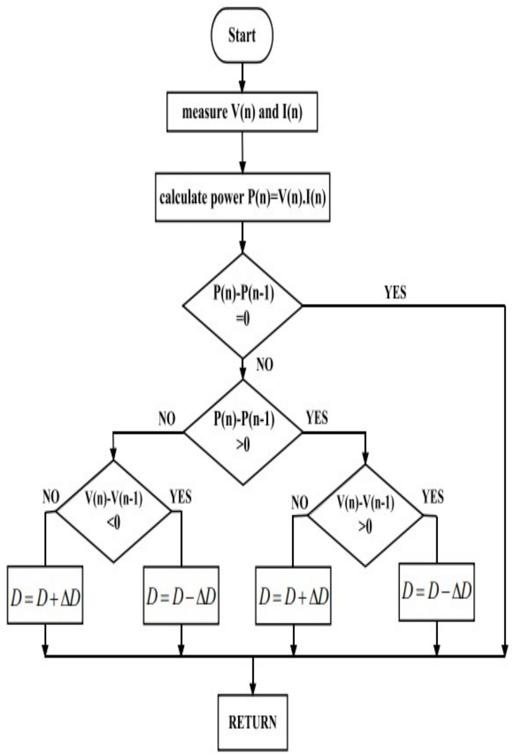

Figure 4: Flowchart of Perturb & Observe MPPT Algorithm.

DVR CONTROLLER- DQ TRANSFORMATION

A 25kV, 100 MVA short-circuit level, equivalent network feeds a 5 MW, 5 Mvar capacitive load. The internal voltage of the source is controlled by the Discrete 3-Phase Programmable Voltage Source block. The programmable source dialog box and look at the parameters controlling the voltage and frequency. A 60 Hz, positive-sequence of 1.0 pu, 45 degrees is specified.

At t = 0.5 s, a sinusoidal modulation of the frequency (amplitude 3 Hz, frequency 0.4 Hz) is started. The modulation stops at t =3 s so that a full cycle of modulation can be observed.

The Three-Phase V-I Measurement block is used to monitor the three load voltages and currents. Open its dialog box and see how this block allows to output the three voltages and currents in p.u.

The Discrete 3-Phase PLL block measures the frequency and generates a signal (wt output) locked on the variable frequency system voltage. The PLL drives two measurement blocks taking into account the variable frequency: one block computing the fundamental value of the positive-sequence load voltage and another one computing the load active and reactive powers. These two blocks and the PLL are initialized in order to start in steady state.

The whole system, (power network, PLL and measurement blocks) is discretized at a 50 us sample time.

DISCRETE PWM-BASED CONTROL SCHEME

In order to mitigate the simulated voltage sags in the test system of each compensation technique, also to compensate voltage sags in practical application, a discrete PWM-based control scheme is implemented, with reference to DVR. The aim of the control scheme is to maintain a constant voltage magnitude at the sensitive load point, under the system disturbance. The control system only measures the rms voltage at load point, for example, no reactive power measurement is required. Figure shows the DVR controller scheme implemented in MATLAB/SIMULINK. The DVR control system exerts a voltage angle control as follows: an error signal is obtained by comparing the reference voltage with the rms voltage measured at the load point. The PI controller processes error signal and generates the required angle δ to drive the error to zero, for example; the load rms voltage is brought back to the reference voltage.

It should be noted that, an assumption of balanced network and operating conditions are made. The modulating angle δ or delta is applied to the PWM generators in phase A, whereas the angles for phase B and C are shifted by 240° or -120° and 120° respectively.

$$V_A = Sin\ (\omega t + \delta)$$

$$V_B = Sin\ (\omega t + \delta - 2\pi/3)$$

$$V_C = Sin\ (\omega t + \delta + 2\pi/3)$$

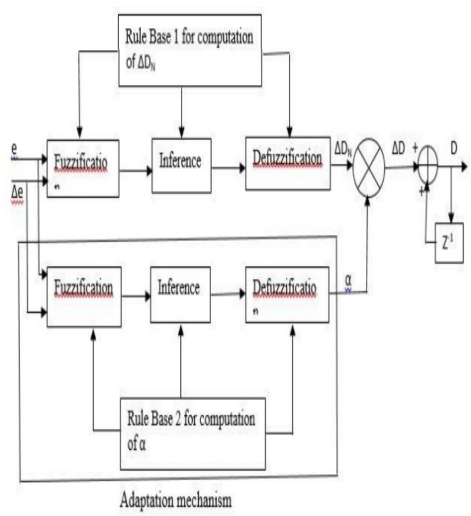

Figure 5: AFLC Control Structure.

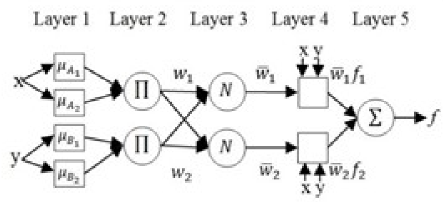

Figure 6: ANFIS Architecture.

Table 1: Two-Pass ANFIS Learning Algorithm

	Forward Pass	Backward Pass
Antecedent Parameters	Fixed	GD
Consequent Parameters	LSE	Fixed
Signals	Node Outputs	Error Signals

Functions of gaussian shape with two parameterscenter (c) and width (σ).

Layer 2 calculates the firing strength of a rule via product operation.

Layer 3 is normalized firing strength of a rule from previous layer.

In Layer 4, each node represents consequent part of fuzzy rule. The linear coefficients of rule consequent are trainable.

Nodes in Layer 5 perform defuzzification of consequent part of rules by summing outputs of all the rules. Further detail on computation performed in ANFIS can be found in the related research.

The two pass learning algorithm tunes consequent parameters by LSE in forward pass and while back-propagating error back to first layer, it updates membership functions using GD. Since, GD is influenced by back propagation (BP) algorithm of ANN, which has the drawback to be likely trapped in local minima [8]. On the other hand, the convergence of gradient method is also very slow; depending on initial parameter values.

CONCLUSION

This paper has presented the power quality problems such as voltage dips, swells, distortions and harmonics. Compensation techniques of custom power electronic devices DVR was presented. The design and applications of DVR for voltage sags and comprehensive results were presented. A PWM-based control scheme was implemented. This characteristic makes it ideally suitable for low-voltage custom power applications. Design and implementation of solar energy-based three phase DVR, using fuzzy logic controlled novel boost inverter, for mitigation of deep voltage sags, swells and an interruption affecting the sensitive equipment connected on low voltage distribution side, has been proposed. The proposed DVR system model utilizes solar energy stored in the battery for mitigation of voltage sags, swells and interruptions hence result in huge cost saving for consumer side and reduces the payback period of the DVR system. It stores the solar energy in separate back up for night time utilization purpose rather than drawing energy from the grid which minimizes the usage of grid energy and increases the reliability of DVR for the consumer. Further fuzzy logic controlled novel boost inverter improves overall efficiency and dynamic performance of the DVR system.

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