Enhancement of Voltage Sag And Swell With ANFIS Based Dynamic Voltage Restorer

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ABSTRACT- In an effort to maintain the three-phase load voltage during rapid grid voltage distortion conditions, such as voltage sag, swell, and imbalance, a dynamic voltage restorer, or DVR, is designed. The DC-link capacitor, which serves as the energy storage component, and the DC\AC inverter make up the DVR. The DC-link capacitor of the DVR provides the instantaneous power to correct or absorb when rapid grid voltage distortion occurs, which leads to degenerate stabilization performance and poor transient voltage quality of the load. Therefore, a key factor in stabilizing the three-phase load voltage is the DVR's DC-link voltage regulation, which keeps the DC voltage constant. In order to enhance the three-phase load voltage and DC-link voltage's rapid reactions during instances of unexpected grid voltage distortion, a unique proportional-integral (PI) controller and an Adaptive-Network Fuzzy Inference System (ANFIS) were utilized for DVR control. The experimental findings are provided to confirm the DVR's viability and efficacy in enhancing the load's transient voltage quality by utilizing the suggested controller.
Keywords: Power Quality, Voltage Sag, Voltage Swell, PI, ANFIS, DVR.

1. INTRODUCTION

One popular method of reducing the aberrant grid voltage is the dynamic voltage restorer (DVR). The DVR's primary purpose is to immediately insert a voltage compensation in series with the source grid that has the precise phase and magnitude. Therefore, in the event of grid voltage sag, swell, or imbalance, the three-phase load voltage can be maintained at a constant and normal voltage level.

The DVR can be divided into two groups according on its structure: 1) A DVR with no energy storage; 2) A DVR using a flywheel, capacitor, or battery for energy storage. The faulty source grid provides the power energy needed for the DVR's voltage correction or absorption without energy storage. As a result, the DVR's cost and power losses will rise in the absence of energy storage. A DVR without energy storage could malfunction because of the malfunctioning source grid connection. However, the AC/DC converter needed to link the DVR with energy storage to the source grid is absent from it. The DC-link battery or capacitor provides the power energy needed for the voltage correction or absorption of the DVR with energy storage. Therefore, the DVR with energy storage is an affordable option because of its straightforward design, The fixed PI gain controller in the conventional system lacks the ability to regulate the voltage of the DC and AC links using a constant reference value. The traditional PI controller, a trial-and-error method, is used to calibrate gain, which takes longer and does not yield well-optimized gain values. Surges and overshoots are also produced as a result. The ideal knob gain of PI controller compensates for DC voltage ripples.

To regulate the DVR compensator, researchers have developed an adaptive controller built on intelligent systems. Because of their self-tuning, self-adaptation, and self-organization, the adaptive controllers minimize the amount of mathematical computation needed for the basic weight extraction. To increase precision, the self-tuned PI controller based on optimization techniques has been used.

2. LITERATURE SURVEY

Kopulwar et al. described using particle swarm optimization in conjunction with PI in DSTATCOM to optimize the electrical noise caused by voltage fluctuations. If the PI gain is successfully changed online and the values are set using the rule. The DC link voltage control system, which uses a two-stage switching power supply based on an LLC resonant converter, was presented by Shih et al. and Wu et al. used the Levenberg-Marquardt back-propagation (LMBP) training algorithm to approximate the error in order to explain the DC link voltage regulation. The online PI control for UPQC tuning has been presented by Dash et al. Adaptive PI controller with self-tuning has been reported by Dheeban et al.

3. PROPOSED SYSTEM

The major significant contribution of the proposed ANN-ANFIS control strategies of DVR in the figure 1 is summed up as: (i) The proposed predictive ANN-ANFIS model is employed for the fundamental weight extraction which is further used for reference generation of load voltage. (ii) DC and AC link voltage regulation is based on ANFIS controllers to improve the PCC voltage profile and circumvent the PQ issues. This automatic gain tuning mechanism improves the DVR performance by reducing the computational complexity, speed learning with least estimated errors and significantly minimizes the time consumption required for trial-and-error process of the PI controller. (iii) The optimized ANN and ANFIS based DVR compensator is integrated with regression technique and designed with fewer rule-based FLC which gives more accurate results over conventional PI controllers in terms of PQ key indices like overshoot, undershoot and settle time. (iv) The performance analysis of the intelligent DVR system is examined on the Matlab/Simulink platform, demonstrating that the developed control scheme outperformed the classical method in terms of computational requirements, swell compensation time, harmonic compensation, dynamic and steady state response etc. at all system dynamical state.

The DVR injects or absorbs reactive power to maintain voltage within acceptable limits during sags and swells. This significantly improves power quality for sensitive equipment. DVRs act swiftly, correcting voltage fluctuations almost instantaneously, minimizing the impact on connected devices.

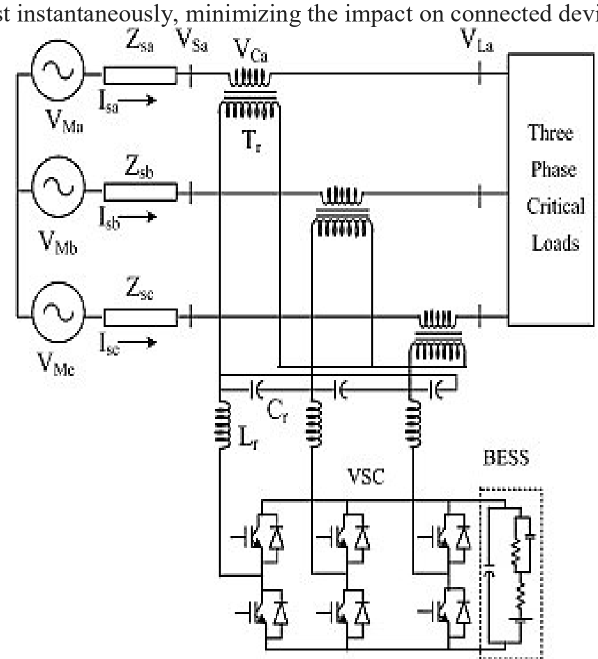

Figure 1: DVR based Power System

Critical loads can "ride through" voltage sags without malfunctioning due to the near-instantaneous voltage correction by the DVR. The system can be adapted to various power ratings, making it suitable for diverse applications, from protecting individual industrial equipment to entire power grids.

DVRs frequently use a hybrid strategy. 1. Supercapacitors: Because of their high-power supply and quick response, they can handle brief voltage variations (milliseconds to seconds). 2. BESS: Uses its better energy storage capacity to provide backup power during prolonged voltage dips, ranging from seconds to minutes. During normal functioning, both systems store energy. Supercapacitors quickly react by spiking their power to offset the initial voltage drop. Then BESS comes on to provide a longer-lasting, consistent voltage adjustment. Voltage Swells by absorbing excess voltage, BESS helps safeguard delicate equipment. Consider a DVR to be your home appliances' voltage stabilizer. Supercapacitors handle abrupt spikes or dips in voltage for a brief period of time, acting as a fast-acting surge protector. When there are protracted voltage disruptions, BESS acts as a bigger backup battery, offering greater protection.

A. Supercapacitor

DVRs (Dynamic Voltage Restorers) can use supercapacitors to solve voltage sags and swells, which are common problems with power quality. Supercapacitors are excellent at providing brief, high-power bursts, which are exactly what's needed to counteract voltage sags. Their ability to charge and discharge quickly allows them to react quickly to voltage changes. But it's crucial to remember that supercapacitors have drawbacks. They have a far lower energy storage capacity than batteries. This restricts their capacity to maintain voltage adjustment over time. As a result, supercapacitors and batteries are frequently utilized in DVRs. While the battery supplies backup power for extended periods of time, the supercapacitor manages transient voltage changes. During regular operation, the supercapacitor serves as the DVR's main energy source, storing energy. A DC-DC converter raises the supercapacitor's voltage to the level that the inverter requires. DC voltage from the DC-DC converter is transformed into AC voltage by the inverter and then sent into the power line. A control system keeps an eye on the line voltage and, if it detects a sag or swell, it instructs the inverter to inject the necessary voltage correction.

In DVRs, supercapacitors have a supplemental role because of their limited energy storage capacity.

B. Battery Energy Storage System

Battery Energy Storage System, or BESS, is the most popular primary energy source for Dynamic Voltage Restorers (DVRs). During regular operation, BESS carefully stores energy, serving as the DVR's primary energy bank. When necessary, this stored energy serves as the foundation for voltage adjustment.

BESS kicks in when there are voltage sags or dips. By releasing the stored energy, the DVR is able to reintroduce the necessary voltage into the power line. By doing this, the sag is counteracted and linked equipment is given a constant voltage supply. In contrast, BESS takes a defensive stance during voltage swells, or spikes. By absorbing excess voltage, it protects delicate electronics. Greater Durability: BESS has a far higher energy density than supercapacitors. This means that voltage adjustment can be maintained for longer periods of time during sags, providing longer protection. Supercapacitors are more expensive per unit of stored energy, despite having faster charge and discharge rates. Long-term, BESS offers a more economical solution. Similar to a sizable rechargeable battery, BESS builds up energy through continuous use. To ensure that the voltage from the BESS meets the needs of the inverter, a DC-DC converter adjusts it. The converter's DC voltage is converted by the inverter into AC voltage that can be injected into the power line. The line voltage is closely monitored by a diligent control system. It tells the inverter to inject or absorb when it detects irregularities.

4. DYNAMIC VOLTAGE RESTORER (DVR)

Injection of compensation voltage with the precise magnitude and frequency is required to restore the load side voltage to the proper amplitude and waveform. The system may inject up to 50% of the normal voltage for a brief period of time (up to 0.1 seconds). Most voltage sags, on the other hand, are much below 50%. Dynamic voltage restoration or control is the term used to describe this (DVR). A dynamic voltage restorer (DVR) is described as the regulating device. End-users who are experiencing power quality problems may benefit from DVRs. Figure 2 depicts a simple DVR power system circuit with a control circuit to inject compensated voltage and maintain the voltage at the correct level. DVRs are often mounted on a crucial feeder, delivering active power through DC energy storage while internally generating the requisite reactive power. In restoring the load side voltage to the required level, a compensating voltage of the required magnitude and frequency must be injected. The system can inject up to 50% of the rated voltage, but only for a brief period (up to 0.1 seconds). Normally voltage sags are far smaller than 50%. A dynamic voltage restorer (DVR) is the regulating device. DVRs may be useful for end-users who are prone to undesirable power quality issues. DVRs are often mounted on the main feeder, delivering active power through DC energy storage and generating the requisite reactive power internally.

A. DVR Operating Modes

A DVR’s switching states are classified into three categories based on operating states: protective, standby, and voltage compensation. In the protective state, if the load current exceeds the allowable value owing to a short circuit or a significant overcurrent current, the DVR will be disconnected from the grid. The inverter shorts the secondary winding of the injection transformer. In the standby state, allowing full load current to flow through the primary winding. In this operation mode, the DVR will not inject any correction voltage into the power grid. The DVR injects the appropriate compensatory voltage via injection transformer to the grid. This mode of operation begins when a load voltage disturbance is detected and terminates when the voltage returns to normal operating conditions.

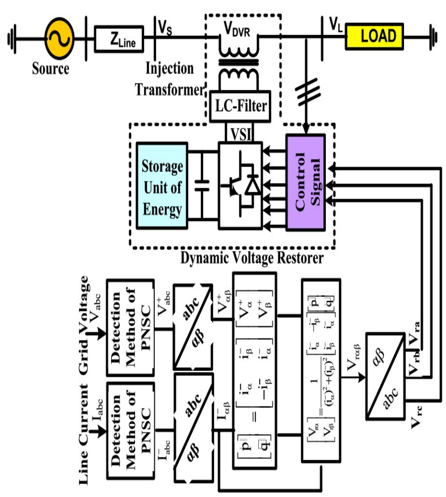

Figure 2: DVR power system circuit with a control circuit

B. Control Strategies and Algorithms of DVR

The detection of voltage disturbances is the major emphasis of the DVR’s control system. Specifically, with sensitive loads, the detecting system should be fast enough to identify the voltage disturbance accurately for the assessment of DVR performance.

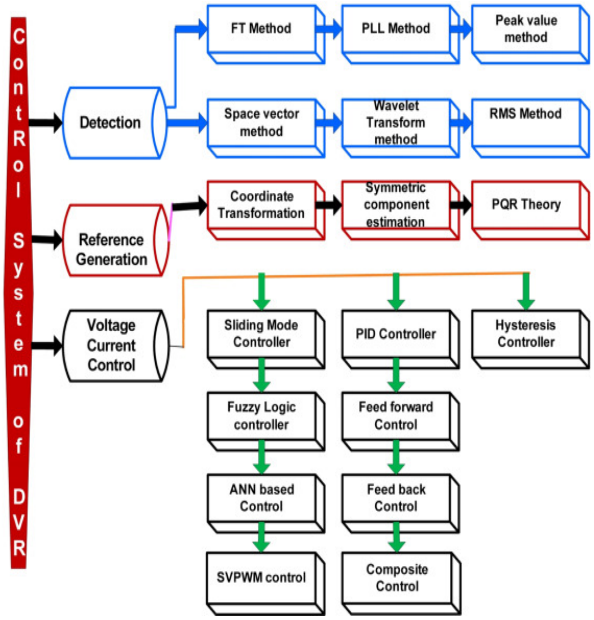

Figure 3: DVR control systems

As shown in Figure 3, various methods for voltage disturbance detection have been proposed, including RMS, Peak Value, DFT, Fourier Transform (FT), Wavelet Transform (WT), Windowed Fast FT (WFFT), ABC to DQ axis transformation, KF, Phase-Locked Loop (PLL), and SRF.

5. SYSTEM DESCRIPTION

The proposed configuration shown in Figure 2 includes a supply (grid) voltage with grid impedance, a three-phase load, an injection transformer, and the DVR system. The DVR system comprises a Voltage Source Inverter (VSI) powered by a DC power source with a dc link capacitor and a harmonic passive filter.

A. ANFIS Architecture

ANFIS architecture is a mapping technique that transforms the existing input to a given output. ANFIS generates refined fuzzy IF-THEN rules, by using fuzzy logic based on human knowledge, to characterize a fuzzy inference system (FIS) with the inputs and output sample data. The main target of ANFIS is to optimize the error between predicted data and ANFIS actual output. FIS-based DVR is required to tackle the complex nonlinear dynamic system. The DC link ANFIS architecture is depicted in Figure 4 and the mapping of the input-output ANFIS structure for AC link voltage.

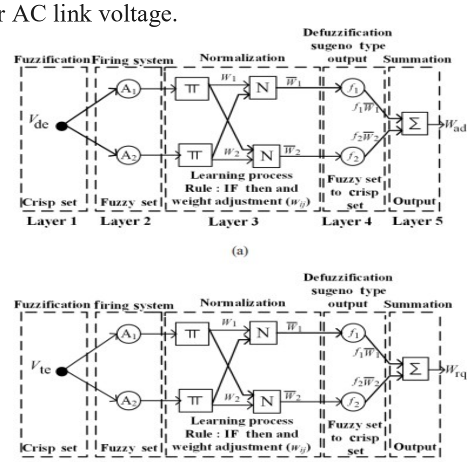

Figure 4: Matlab structure for ANFIS (a) DC link and (b) AC link.

B. ANFIS Learning Algorithm

ANFIS integrates the merits of back-propagation (BP) and least square approximation (LSA) which facilitates the self-learning of the network. It is believed that the ANFIS has only one output (Y) under the LSE learning algorithm. This hybrid ANFIS algorithm is not only efficient to optimize the search space dimension but also minimizes the convergence time. The smaller the value of measuring criteria, the best fitted and reliable model is obtained with higher accuracy. The fitness function is the error minimization considered for DC link (Vdc) and RESULT AND DISCUSSIONS

A detailed simulation of the DVR control system was performed using the MATLAB program in order to verify the operation. In order to understand the performance of the DVR along with control, in voltage sags and swells mitigation, a simple distribution network is simulated using MATLAB. Voltage sags and swells are simulated by temporary connection of different impedances at the supply side bus. A DVR is connected to the system through a series transformer with a capability to insert a maximum voltage of 50% of the phase to ground system voltage. Apart from this, a series filter is also used to remove any high frequency components of power. The load considered in the study is a 5 KVA capacity with lagging power factor.

A. Voltage sags

The first simulation of three phase voltage sag is simulated and a 50% three-phase voltage sag occurring at the utility grid is shown in Figure-5 (a). In Figure-5 (a) also shows a 50% voltage sag initiated at 0.1s and it is kept until 0.3s, with total voltage sag duration of 0.2s. Figures-5 (b) and (c) show the voltage injected by the DVR and the corresponding load voltage with compensation. As a result of DVR, the load voltage is kept at 1 pu. The effectiveness of the DVR under unbalanced conditions is shown in Figure-6, in Figure-6 also shows the occurrence of 50% single phase voltage sag on a utility grid. Through simulation the supply voltage with one phase voltage dropped down to 50% as shown in Figure 6 (a). The DVR injected voltage and the load voltage are shown in Figures 6 (b) and (c) respectively. Its corresponding load voltages are shown in Figure 6(c) where it is possible to see that the compensation method is keeping the load voltages constant at 1 p.u.

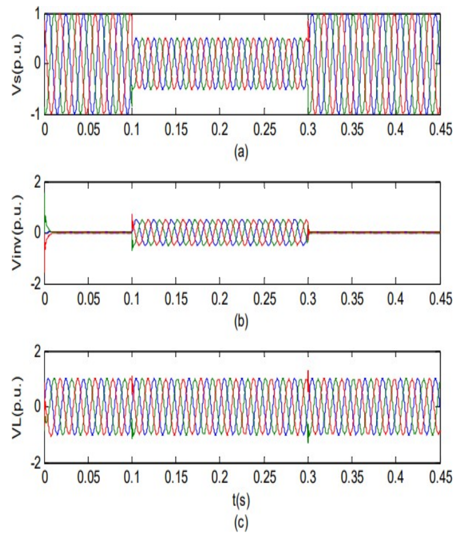

Figure 5: Three-phase voltages sag: (a)-Supply voltage, (b)-voltages injected by the DVR, (c)- voltage at load.

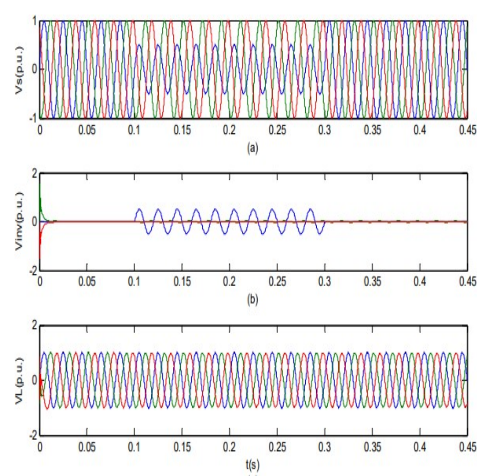

Figure 6: Single-phase voltage sag: (a)-supply voltage, (b)-voltage injected by the DVR, (c)- voltage at load.

B. Voltage Swells

The second simulation shows the DVR performance during a voltage swell condition. The simulation started with the supply voltage swell generated as shown in Figure 7 (a). The amplitude of supply voltage is increased about 25% from its nominal voltage. (b) and (c) show the injected and the load voltage respectively. As can be seen from the results, the load voltage is kept at the nominal value with the help of the DVR. Similar to the case of voltage sag, the DVR reacts quickly to inject the appropriate voltage component (negative voltage magnitude) to correct the supply voltage. The performance of the DVR with an unbalanced voltage swell is shown in Figure 8. In this case, two of the three phases are higher by 25% than the third phase as shown in Figure 8 (a). The injected voltage that is produced by DVR in order to correct the load voltage and the load voltage are shown in Figure 8(b) and (c), respectively.

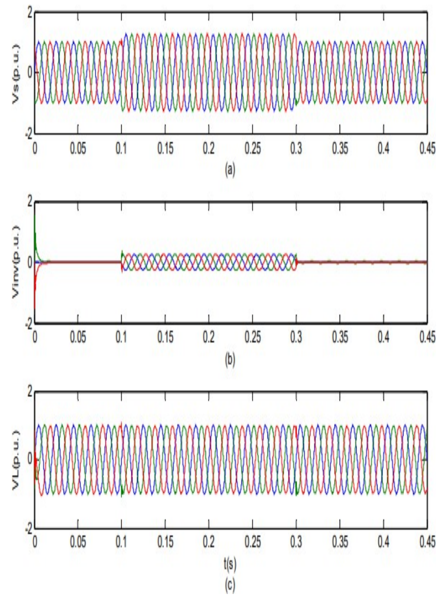

Figure 7: Three-phase voltages swell: (a)supply voltage, (b)voltage injected by the DVR, (c)- voltage at load.

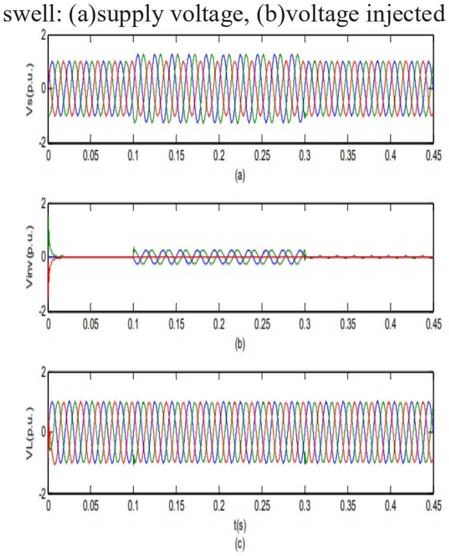

Figure 8: Two-phase voltages swell: (a) supply voltage, (b) voltage injected by the DVR, (c)-voltage at load.

6. CONCLUSION

In order to stabilize the three-phase load voltages during grid voltage sag, swell, and imbalance conditions, a DVR has been successfully built and placed into operation. A novel PI and ANFIS controllers for the DC-link voltage control and the compensation strategy were needed because the power energy that followed into or out of the DVR's DC-link capacitor caused degenerate stabilization performance and a poor transient response under conditions of sudden grid voltage distortion. The experimental findings show that the transient responses of the three-phase load voltages and the DC-link voltage of the DVR are effectively enhanced and stabilized because of the suggested controller's powerful robust ability and online learning capability.

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