Control of DVR by Fuzzy Controller to Improve Voltage in Distribution System

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Abstract

With the development of critical loads, power quality problem has become particularly important and poor power quality will be cause many adverse effects and the cost of many deaths will follow. To improve power quality and protection of sensitive loads against grid disturbances have been used new equipment based on power electronics similar FACTs devices, they are Custom Power. One of the most important Custom Power Device is DVR that it is used for compensation Swell and Sag voltage in the distribution network. The DVR injected voltage to compensate for the Swell and Sag voltage in distribution network. Compensation voltage accuracy depends on by its ability to design PWM, the controller and choice of filter parameters. For control of DVR can be used traditional controller, such as PI, PID and intelligent controller, such as fuzzy controller. In This paper, Fuzzy controller is used for controlling DVR in the Distribution Network.

Keywords Fuzzy Controller, Sag Voltage, Compensation, Custom Power Devices, DVR
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1. Introduction

Variable nature of loads has increased the expectations of customers for having a high quality of electricity. Temporary interruptions and voltage disturbances or distortion in the voltage waveform are destructive for modern loads. Expansion of the electrical quality pollution can cause a lot of problems, therefore prevention and modification of network is very necessary. So changing of network structure, modification and optimization of network and proper operation are logic solutions. But generally, three solutions can be offered to refine the power quality pollution:

- Removing or improving the disturbances
- To remove or modify paths of the source of disturbances
- Using compensator sources [1, 2]

One of the most important ways for improving the quality of electricity and reducing losses in distribution networks is the using of power electronic technology in the form of custom power devices. Custom power devices are divided into two major categories:

- Devices without DC power supply
- Devices with DC power supply

DVR is one of the most important custom power devices that are used to compensate sensitive load voltage, which can eliminate swell, sag, harmonics and flicker of voltage.[3]

Sag of voltages can cause disruption and decreasing of product in industry. Recent research shows that 92% of disturbances in distribution networks are due to voltage sags. The voltage swell is not as important as the voltage sag, because voltage swell happens in distribution systems rarely. Swell or sag of the voltage in sensitive loads can cause an error and or Fuses and switches may act due of high unbalance of current under the rated current.

There are several methods to compensate sags or swells of voltage but using of DVR is a suitable method. The commonly controller for DVR is the PI controller that it has a simple structure. The main problem of this controller is the correct selection of the gains that it may controller does not provide the required control, so to solve these problems, the using of fuzzy controllers is proposed. [4, 5]

2. Dynamic voltage restorers (DVRs)

With the increasing application of electronic devices and other power quality sensitive equipment, it is inevitable to produce the desired quality of power for consumers.

Custom power devices were introduced to improve power quality in the 1980s.

The DVR is a series compensators of custom power that It is used to compensate for the increase or decrease of voltage.[4]

When voltage reduces in network, this devices control amplitude, phase and frequency, and establishing voltage by inject of voltage.

Therefore the performance of DVR is based on the voltage injection at during of voltage drop. In general, the DVR operation is divided into three modes:

- Protection mode
- Standby mode
- Injection mode[6]

A) DVR structure

The main part of the DVR is the VSI converter, which converts the DC voltage to the AC voltage with desired the amplitude, phase, and frequency. The output of converter is non-sinusoid and has specific harmonics that can removed them by using multi-level converters with continuum arrangements and applying advanced PWM techniques and installing suitable LC filters on the load side or between the converter and transducer. The basic structure of a DVR consists of six parts, as shown in Fig.1.

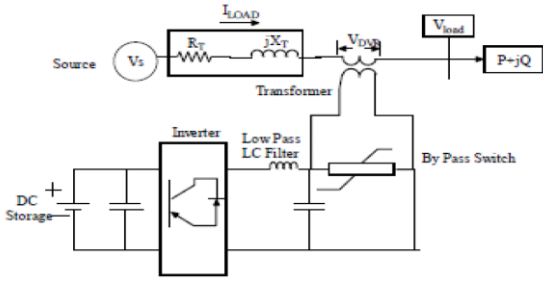

Fig. 1. Elements of DVR

The elements of DVR are:

- DC power storage unit
- DC capacitor
- Inverter or voltage source converter
- Pass filter (passive)
- Bypass switch
- Voltage Transformer [3]

In a three-phase system, one of the two conditions below is for injection of required voltage:

- Three single-phase transformers
- A three-phase transformer

The injection transformer duty is to isolate the DVR from the network voltage and increase the DVR generation voltage level, and it is linked in series between distribution network and load. The high voltage side of transformer is connected series to the distribution network, and the weak voltage side connects to the DVR power circuit. Three single-phase transformers can be used to connect DVR to distribution network and the primary transformer is delta or star as in Fig. 2.[6]

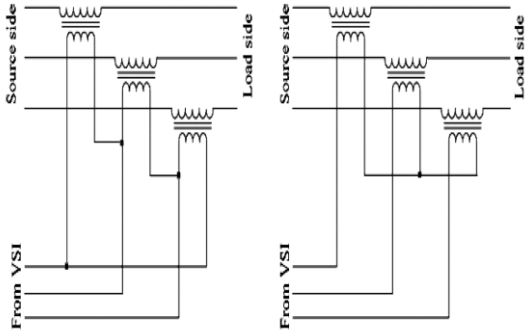

Fig. 2. Trans-injection method of connecting the star and triangle

B) Control system (protection and control system)

The control system is measured and analyzed the supply and load voltage at any moment for proper operation of the DVR, and compares with the reference value, and in the event of any disruption, system control is applied the necessary control for injection voltage.

Pulse width modulation control technique is used for switching and generating 50 Hz sinusoidal voltage at the load terminals.

The basic role of control system in the DVR is detected swell and sag and then determine the value of required voltage to compensate.[6, 7]

3. Design of the studied fuzzy system

The fuzzy controller consists of four parts:

- Fuzzifier
- Fuzzy Knowledge Base
- Inference Engine
- Defuzzifier

Fig. 3 shows the fuzzy controller structure.[8, 9 , 10]. Fuzzy controllers are nonlinear controllers with specific structure. Fuzzy logic control does not need an accurate mathematical model, can work with imprecise inputs, can handle nonlinearity, and can present disturbance insensitivity greater than the most nonlinear controllers. Fuzzy logic controllers usually outperform other controllers in complex,

nonlinear, or undefined systems for which a good practical knowledge exists.

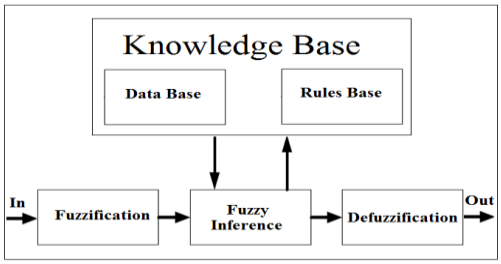

Fig. 3. The structure of fuzzy controller

In this paper, the sugeno fuzzy model is used that it has two input (error and error derivative) and one output (control signal).

This control system has two input variables called error (e) and error variations (error derivative) (Δe) and an output variable called control signal (Y).

Fig. 4 shows inputs and output of selected model in the MATLAB.

Three membership functions of error variable are M1, M2, and M3. Membership functions of error derivative are M1, M2, and M3. Output of this system has 9 fixed functions that they are Y1, Y2, Y3, Y4, Y5, Y6, Y7, Y8 and Y9.

Fig. 5, 6 and 7 show the linguistic variables, the shape, and the number of selected membership functions. The fuzzy rules designed for this controller are shown in Fig. 8.

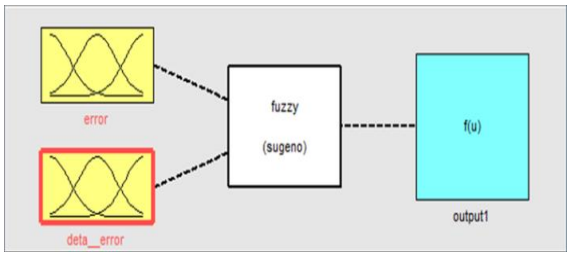

Fig. 4. The fuzzy system is selected

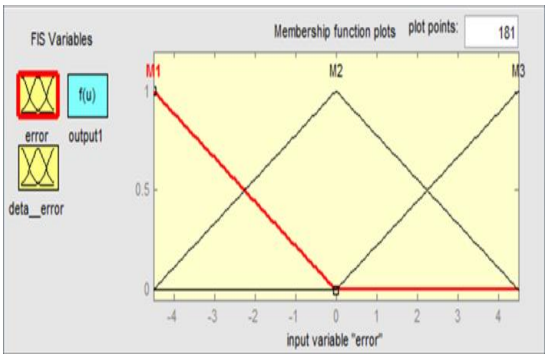

Fig. 5. The triangular membership functions of input(error)

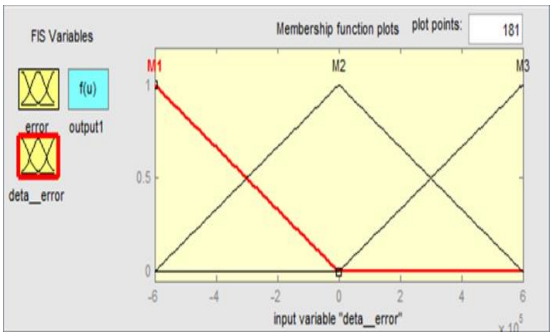

Fig. 6. The triangular membership functions of input (delta_error)

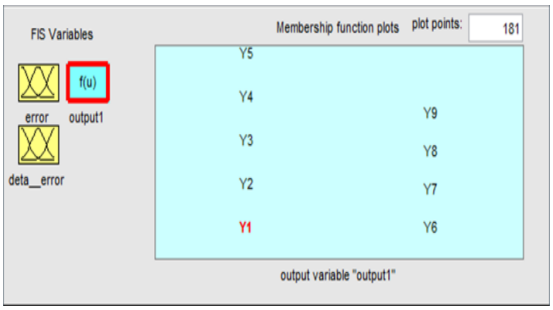

Fig. 7. The output membership functions for fixed functions

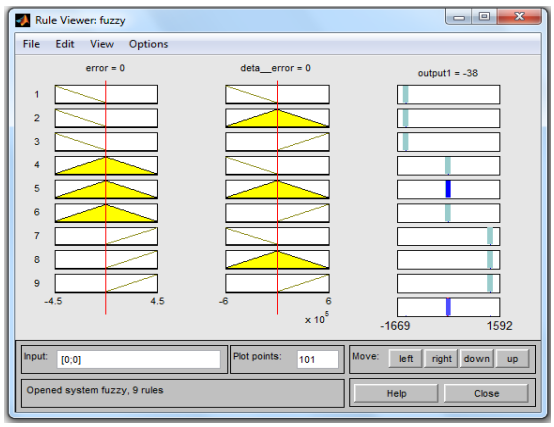

Fig. 8. Fuzzy rules in GUI MATLAB

4. Simulation and Case Study

Before installing DVR in distribution network, two issues should be reviewed and evaluated:

- The problem of analysis and power quality indicators
- Selection of capacity and Optimal location[3]

Electronic devices are very sensitive to disturbances and the issue of power quality and providing the proper voltage is essential for them.

In the competitive environment of the industry, with development use manufacturing units from power electronic devices, computer processors, nonlinear loads and any interruptions or changes

(outside) beyond the standard in the quality of delivery power will cause economic losses. Therefore, access to quality electricity has a significant impact on saving capital for a production unit.It's been years that the control of processes and industrial systems was done by experts with the PID controller.

The reason for using these controllers is simple, low cost design and effective role in all working condition and also PID controllers are used to a lot of in industrial technology. Many processes controlled by human operators in industry cannot be automated using conventional control techniques, since the performance of these controllers is often inferior to that of the operators.

One of the reasons is that linear controllers, which are commonly used in conventional control, are not appropriate for nonlinear controllers. Another reason is that humans aggregate various kinds of information and combine control strategies, that cannot be integrated into a single analytic control law.

The underlying principle of knowledge-based (expert) control is to capture and implement experience and knowledge available from experts. A specific type of knowledge-based control is the fuzzy rule-based control, where the control actions corresponding to particular conditions of the system are described in terms of fuzzy if-then rules. Fuzzy logic can capture the continuous nature of human decision processes and as such is a definite improvement over methods based on binary logic.

In most cases a fuzzy controller is used for direct feedback control. However, it can also be used on the supervisory level as, e.g., a self-tuning device in a conventional PID controller. Also, fuzzy control is no longer only used to directly express a priori process knowledge.

A) Case Study

The distribution network studied has following characteristics.
Distribution network specifications(characteristics):
Voltage of source: V_{source} = 220 v
Frequency: f = 50Hz
Specific Load Specifications of studied:
Voltage of load: V_{load} = 220 v
Power of load: P_{load} = 80 KVA
Power factor of load: PF = 0.92 Lagging
The network studied has shown in Fig. 9, which is derived from a distribution network.

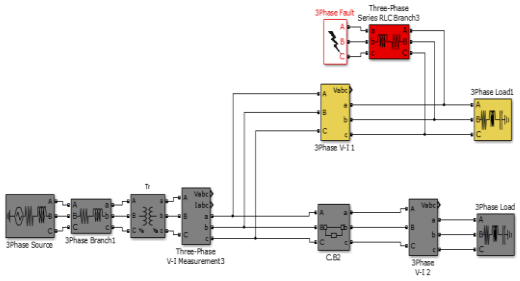

Fig. 9. Studied the distribution network with certain load

It has two loads, one of the loads is a special load, and drop of voltage is compensated by the DVR in the voltage drop conditions.

This drop of voltage (sag) is usually between 0.1 to 0.9 rated voltage.

Fig.10 shows the internal structure of the DVR.

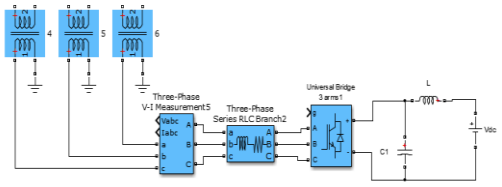

Fig. 10. DVR internal structure of the study

This DVR has the following characteristics: Battery Direct Voltage: VDC = 850 v Coupling Transformer Type: Three Single-Phase Transformers with conversion ratio N1 / N2 = 1: 1 Capacitor Bank Capacity: C = 8.8 mF Series resistance Rd = 0.1 Ω and inductance L = 1 mH
Type of inverters: IGBT Three Bridge Output filter capacity: LC = 80 µF The primary of coupling transformer is a star and the secondary of it is series with the network.

B) DVR control plan(design)

The block diagram of the DVR control is shown in Fig. 11 and 12.

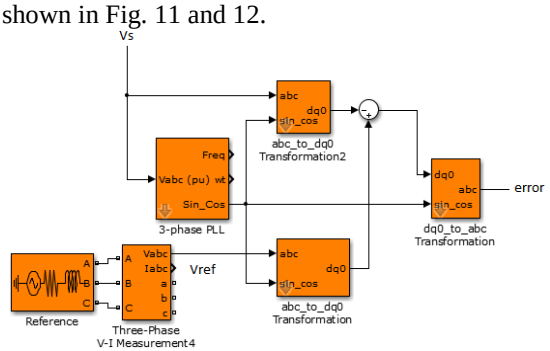

Fig. 11. PLL converter

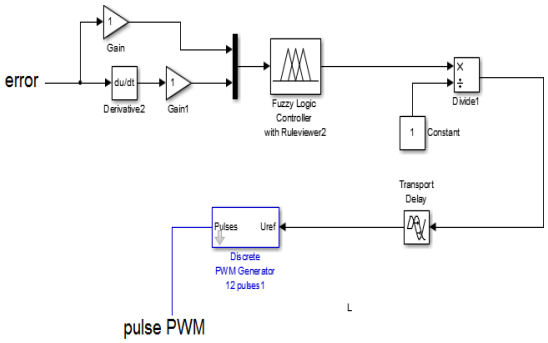

Fig. 12. Fuzzy controller for DVR

In this design, the three-phase feeding voltages are converted to dqo values And then these values are compared with reference values V_d and V_q then voltages error of d and q are obtained.

Then these dqo values are converted to abc values and applied to the controller. Controller output is sent to PWM to generate signal. Input of fuzzy controller is the error(V_{ref}-V_{load}). This error is obtained by comparing the dqo components of reference source and load. This error and its variations are applied as two inputs to the fuzzy controller and the fuzzy controller applies its output to the PWM converter. Converter of PWM is excited and generates modulated pulse and sents it to inverter. The p converter has three bridges of six pulses. Its switching frequency is 1200 Hz. The carrier frequency is 12,000 Hz.

C) Simulation Results

The system studied and its control circuit shown in Fig. 13 and this system is a fed one-way system. In this system, in the event of fault or connecting capacitor bank to system is created sag or swell voltage. This error is detected by the controller and compensated. Efficiency of the proposed scheme of DVR control is discussed in during voltage sag at symmetric three-phase fault. This network is simulated in normal and symmetric three-phase fault conditions. Fig. 14 shows voltage waveform of the source terminals in sag state.

This voltage drop may be between 0.1 and 0.9 of the rated voltage. Fig. 15 shows voltage waveform generated by DVR that range of this voltage is from 0.1 to 0.9 rated voltage.
The DVR voltage equation is as follows:

$$V_{DVR} = V_{LOAD} + Z_{LINE} I_{LOAD} - V_{SOURCE}$$

(V_{LOAD} = Voltage of load, Z_{LINE} = Line Impedance, I_{LOAD} = Load Current and V_{SOURCE} = Source Voltage during fault conditions)

Fig. 16 shows waveform of load voltage in compensated conditions that The voltage is compensated for the fault state and is equal to the rated voltage. This voltage is sum of two voltage, drop and DVR output.

5. Conclusion

The main function of a DVR is the protection of sensitive loads from voltage disturbances coming from network. The types of voltage disturbances such as voltage sags or swells, transients, unbalanced voltage and harmonics DVR . can mitigate the some types of power quality disturbances such as voltage sags/swells, voltage harmonics and unbalances.

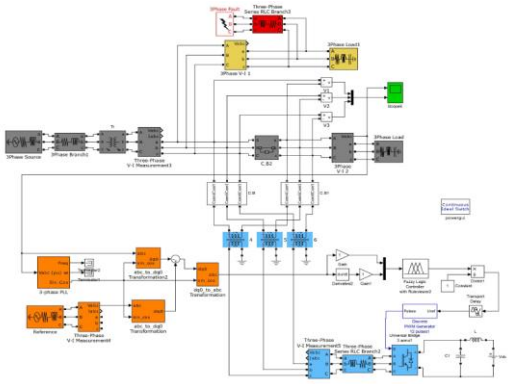

Fig. 13. Full control circuit with studied the distribution network

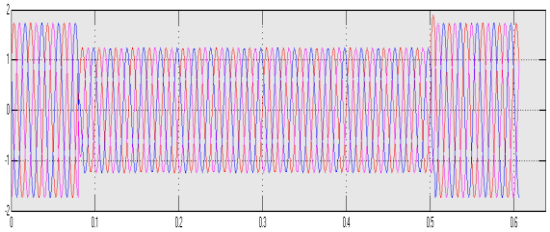

Fig. 14. The voltage waveform power supply terminal In terms of voltage sag(without DVR)

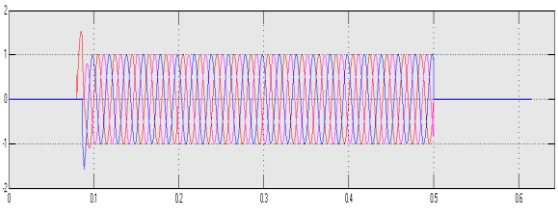

Fig. 15. Voltage waveform generated by the DVR

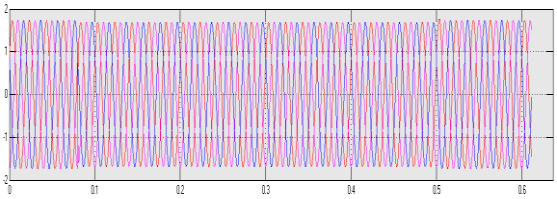

Fig. 16. Load voltage waveform compensated by DVR

The main advantages of DVR are low cost, simpler implementation; require less computational efforts and its control is simple as compared to other methods. There are several methods to control DVR, one of them is nonlinear controller. Fuzzy controller is one of the nonlinear controllers that is used in this paper. The advantage of this controller is the ability to change its rules and It can be improved and or optimized it with Optimized algorithms and Also, it does not require mathematical equations and modeling. In this paper, the DVR has shown the ability to compensate for voltage sags at the load side, this can be proved through simulation. In this paper, the simulation of a DVR with a fuzzy controller was done in Matlab / Simulink.

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