



Enhanced Microgrid Protection Against Transient Faults Using Dvr Active Filtering

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Abstract: This paper presents a comprehensive approach to enhancing microgrid protection against transient fault using Dynamic Voltage Restorer (DVR) active filtering. Transient faults in Microgrid is lead to power quality issues, equipment damage, and even system instability. The proposed method utilizes DVR active filtering to detect and mitigate transient faults, ensuring reliable and resilient microgrid operations. The approach is validated through simulations and experimental results, demonstrating improved fault ride through capability and reduced voltage sag during transient faults. The paper also discusses the benefits of integrating DVR active filtering with existing microgrid protection schemes to enhance overall system performance and reliability.

Index Terms – DVR active filtering, Microgrid protection, Grid stability, Power quality improvement, PID controller, Fuzzy Logic, Adaptive control

I. INTRODUCTION

The global demand for energy has surged in recent years, leading to a growing trend of developing Microgrids (MGs) in the energy sector worldwide. Microgrids are designed to enhance the efficiency of power supply at the local community level. Typically connected at low-voltage levels, they can sometimes be linked to medium voltage levels, particularly when integrated with Distributed Energy Systems (DESs) like microturbines, fuel cells, and solar panels (PVs). These systems are often paired with energy storage solutions such as batteries, flywheels, energy capacitors, and flexible loads to improve performance.

Microgrid is a smaller version of the subsisting centralized electricity system, because microgrids too regulate and distribute the flow of electricity to consumers like the subsisting power grids. But unlike the conventional system, it is done locally. It is a single controlled unit in a power system that can be considered as a single aggregated load. “positioned at any location in the microgrid without reconstructing of protection scheme. This capability facilitates the installation of incipient DG sources and reduces the possible engineering errors in the microgrid.

Modes of operation: A microgrid can operate in two different modes either grids connected or islanded operation mode. The operational requirements are different for each operating mode.

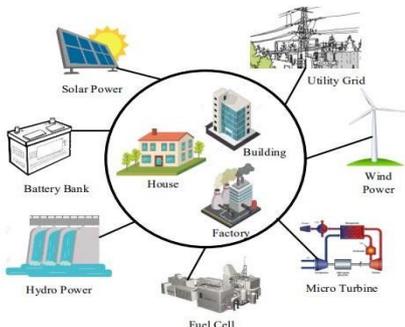


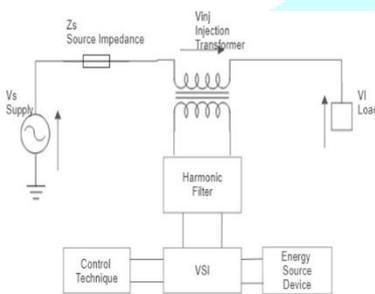
Fig 1.1: Structure of Microgrid

▪ These modes are as follows:

1. **Grid-connected mode:** It is the normal operating mode without any power quality perturbation on the main grid. During this mode, depending on the total power generation of the local load, microgrid may either import or export power to the main grid and may provide power supply to its entire local load. In this mode, bidirectional power flow is also maintained by the microgrid.
2. **Islanded mode:** Whenever a power quality perturbation or fault occurs on the main grid, microgrid detaches from the main grid and function autonomously. If there is a problem of power interruption in the main grid, microgrid will maintain high quality of power and may provide continuous supply to the consumers. Furthermore, if other disturbances like frequency drops, voltage sags or any fault occur in the main grid, then the microgrid can be facilely separated.

DYNAMIC VOLTAGE RESTORER (DVR)

A Dynamic Voltage Restorer (DVR) is a device designed to protect sensitive equipment in power systems from voltage sags or short-duration interruptions. Voltage sags, or dips, happen when the voltage temporarily drops below the normal operating range, typically due to faults, load switching, or other disturbances in the power system. The main role of a DVR is to rapidly restore the voltage to its nominal level during these sags, preventing potential damage, malfunction, or production delays to the equipment. The DVR is a voltage-based compensation device that integrates inverter, switching, and energy storage technologies. It consists of five components: a series injection transformer, an LC harmonic filter, an inverter device (PWM DC to AC), an energy storage system, and a control circuit. A schematic diagram of the DVR is shown in the figure.



Series Injection transformer

The series injection transformer is a specially designed transformer (either single-phase or three-phase) with a delta connection, used to inject compensation voltage to the load side. This transformer serves two main functions:

Coupling and Protection Function: The transformer connects the DVR to the distribution network via its primary winding. It helps reduce noise coupling and transient energy transfer from the primary to the secondary winding.

Voltage Injection: It transforms and couples the compensation voltage generated by the DVR for injection into the system.

Fig 1.2: Block diagram of DVR

LC harmonic filter

The LC harmonic filter consists of an inductor and capacitor connected in series. Its main function is to prevent the harmonic voltage generated by the inverter device from exceeding permissible limits. It operates by filtering out high-frequency components during harmonic switching, ensuring that the system remains within acceptable voltage limits.

Inverter device

The inverter is a power electronic device that converts DC to AC at the desired magnitude and phase. In this study, the conversion of DC voltage to AC is achieved using a 3-phase full bridge with 6-pulse switching of IGBT, employing the Pulse Width Modulation (PWM) technique. The sinusoidal voltage produced by the inverter serves as the voltage compensation, which is then passed through the LC harmonic filter and transformer before being injected into the sensitive load side.

Energy storage system

The energy storage system is responsible for storing energy in DC form within the system. Several energy storage devices can be used, including Superconducting Magnetic Energy Storage (SMES), lead-acid batteries, super-capacitors, and flywheels. These devices are crucial for supplying the real power requirements of the system when the DVR is used for voltage compensation. In this paper, a battery is employed as the energy storage device.

Control Circuit

The control system of a DVR is crucial, as it ensures a fast response to voltage sags and fluctuations in the connected load. The basic functions of the DVR control system are:

- **Detection of Voltage Sag:** Identifying voltage sags occurring in the system using the Synchronous Reference Frame (SRF) method.
- **Conversion to dq0 Reference:** Converting the detected voltage sag to a dq0 reference frame using Park's transformation theory.
- **Calculation of Compensation Voltage:** Determining the required level of compensation voltage.

- Generation of Trigger Signals: Creating trigger signals for the PWM inverter to activate the compensation.
- Voltage Injection: Injecting a sinusoidal voltage to restore the voltage and compensate for the sag.

II. DVR TUNED WITH FUZZY LOGIC

Why Use Fuzzy Logic with DVR?

1. Handling Uncertainty in Voltage Sags:
 - Voltage sags can vary in duration, magnitude, and frequency. Traditional methods like PID control might struggle to handle such varying conditions due to their rigid structure.
 - Fuzzy logic allows the system to be more flexible, reacting to different levels of voltage sag severity and compensating accordingly.
2. Improved Response:
 - Fuzzy logic controllers can fine-tune the response based on real-time system conditions, allowing for more accurate voltage compensation.
 - The fuzzy system doesn't require precise model parameters, making it well-suited for systems with uncertainties or complex dynamics.
3. Dynamic Adaptation:
 - Unlike conventional controllers, fuzzy logic controllers can adapt dynamically to changing system states. For example, during a deep voltage sag, the fuzzy controller might provide a stronger compensating voltage than during a shallow sag.

How Fuzzy Logic Works with DVR:

In a fuzzy logic-based DVR system, the fuzzy controller determines the compensating voltage to inject during a sag event. Here's how it works:

1. Detection of Voltage Sag: The DVR continuously monitors the input voltage and detects any sudden drops (voltage sags). The input voltage is compared to the desired setpoint (nominal voltage), and an error value is calculated.
2. Fuzzification: The error signal (the difference between the nominal voltage and actual voltage) is converted into fuzzy terms such as "low," "medium," or "high." Other input parameters like sag duration and rate of voltage change can also be fuzzified.
3. Fuzzy Rule Base: A rule base consists of IF-THEN rules that determine how the DVR should react to different levels of voltage sag. Example Rules: i) IF the voltage error is "high" AND the sag duration is "long," THEN increase compensating voltage. ii) IF the voltage error is "low" AND the sag duration is "short," THEN apply a slight compensating voltage. These fuzzy rules are based on empirical knowledge or system performance requirements.
4. Inference Process: The fuzzy inference engine evaluates the fuzzy inputs using the rule base to generate fuzzy outputs. These outputs represent the amount of voltage compensation required. For example, a rule might infer that "If the voltage sag is large and sustained, inject a high compensating voltage."
5. Defuzzification: The fuzzy outputs are then converted (defuzzified) into a crisp control value that specifies the exact compensating voltage to inject. One common defuzzification method is the centroid method, which calculates the centre of gravity of the fuzzy output.
6. Compensating Voltage Injection: The DVR uses the defuzzified control value to inject the required compensating voltage into the system to restore voltage levels and mitigate the sag.
7. System Recovery: Once the voltage sag is corrected and the system returns to normal, the fuzzy controller gradually reduces the compensating voltage to zero, avoiding overshoot.

Step-by-Step Example:

Step 1: Voltage sag is detected. Suppose the sag is 20% below the nominal voltage.

Step 2: The fuzzy logic system takes inputs: Voltage error: High (since the voltage is significantly below the nominal value). Sag duration: Medium (the sag lasts for a moderate amount of time). Rate of voltage change: Slow (the voltage drop is gradual).

Step 3: The fuzzy system evaluates the rules and determines: "IF voltage error is high AND sag duration is medium, THEN compensating voltage is high."

Step 4: The fuzzy output is defuzzified into a crisp value, e.g., 90V (compensating voltage).

Step 5: The DVR injects the compensating voltage of 90V, restoring the system to its nominal voltage.

III. SIMULATION AND RESULTS

MATLAB Simulink will be used in this work to perform the simulation. A DVR is connected to the system through the series transformer which is tuned with FUZZY logic control.

The left side of the simulation contains the generator of 11 KV and symbolically stepdown transformer to represent it as a secondary distribution system to understand the working of the system at the final DISCOM level.

The left side contains the RLC load to represent the realistic load and system scenario and it will switch randomly or with the step time to show the variable load (from 5KVA to 40 KVA variable) The DVR with fuzzy has been place below and it is feeding the controlled voltage in the distribution grid via a battery as a source and a passive capacitor to stabilize the outcome of the DVR. Overall the tuned is main and the switching of the DVR has been controlled by the Fuzzy logic.

The various fault like PID has been placed in the grid to represent the actual fault system, which can be shows as the LG, LLG, LL and so on, which could be taken as in real scenario as a tree branch to ground, line to line in wind or storm or a line break to other line of touch the RSJ pole and so on.

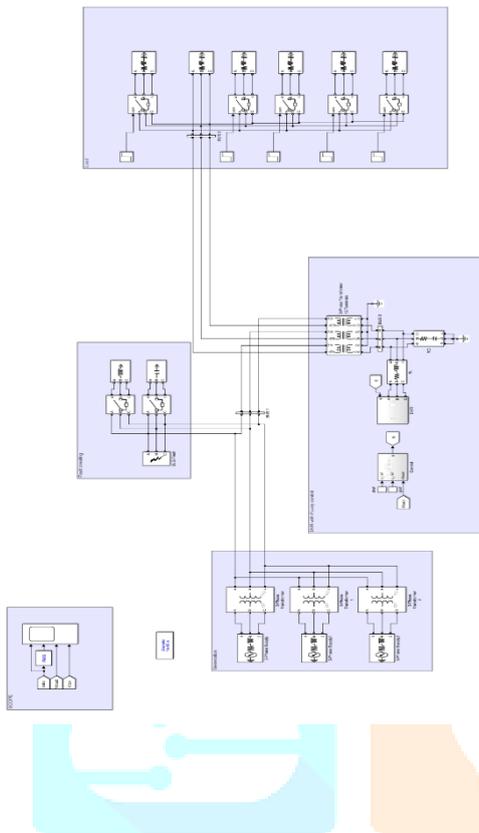
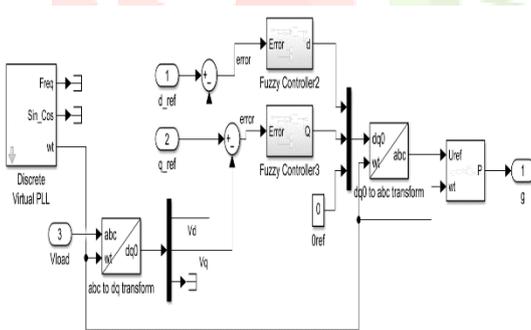


Fig.3.1 Simulation model of Microgrid protection using DVR filter tuning with Fuzzy logic



Controller to provide an error signal to the fuzzy logic and the output given to the pulse generator to provide to DVR controller which convert backup battery voltage to the required pulse to stabilize the system during fault, and load variable condition, and make it recover much smoother and faster.

The basic Clark-park method has been implemented in the system. So, ABC to DQ and after fuzzification and defuzzification it converted DQ0 to ABC and given to the pulse generator.

Fig.3.2: DVR controller with Fuzzy

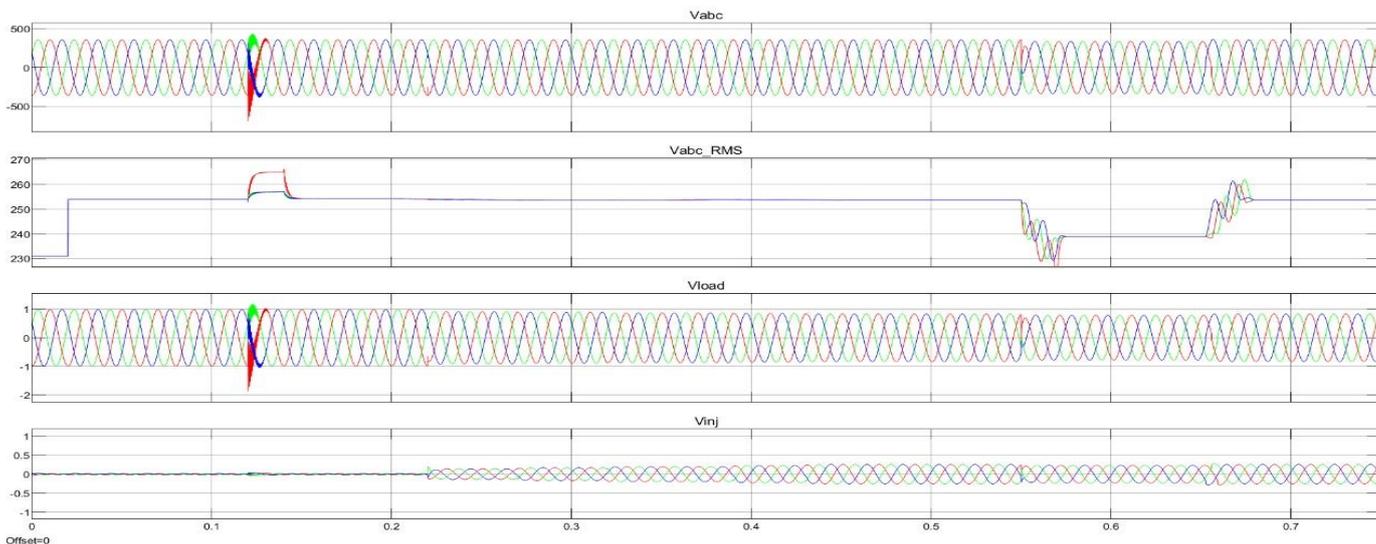


Fig.3.3: Output Waveform

The overall scope of the simulation has shown the best outcome from the generator side to the load side and DVR injection. The first is load side, where the various types of unhealthy conditions have been introduced, from heavy inductive and capacitive fault at .12 second to LG fault between .55 to 0.66 second. The variable loads have been introduced from 0.22 seconds to 0.7 second, which shows the minimal impact on the load side as well as source side while the DVR voltage injection keep changing to make the system stable as much as possible. As the FFT analysis will show. The Vrms of the grid has shown the impact, while the graph clearly shows that the impact is very minimal even in the fault condition, which is one of the best thing about DVR over STATCOM, as it keep injecting the voltage required and make the system stable, but the limitation is the availability of battery power, if the battery replaced by the DG set it could be run much longer. But the high load and low battery could unstable the system in which case an additional system could disconnect the non-priority loads from the grid to make the and keep the system stable in the future scope.

The FFT analysis has clearly proven that within a cycle of instability the system regained the THD below 5% which is acceptable as per the IEEE standard and which makes the DVR with the fuzzy logic much better.

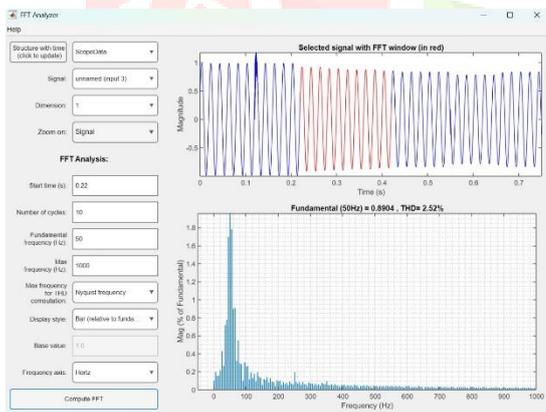


Fig.3.4: FFT Analysis

Overall the system is much stable compared to its previous model with PID, considering the fuzzy and the implementation of DVR over other active filter, the system remains stable. As overall 100 KVA system of the distribution grid remains stable with only 25 KVA DVR system, which could be also works as a backup power to the grid for a very short period of time considering the load at the time and the required power at the priority bases. Overall the system cleared its aim of stabilizing the distribution grid effectively with the additional features of the backup power for the short duration.

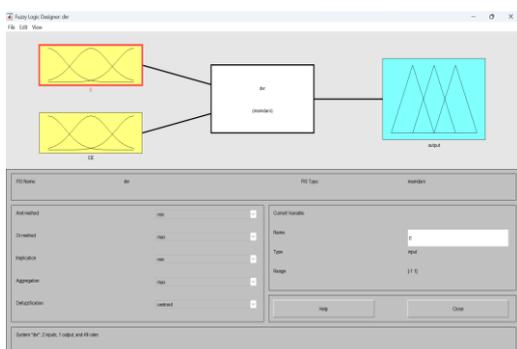


Fig:3.5 Input 1 from error and 1 output to the controller from the desire actual to tuned the output

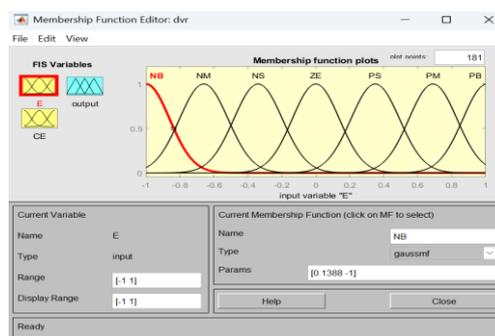


Fig:3.6 Input 1 as an error checker to for pulse.

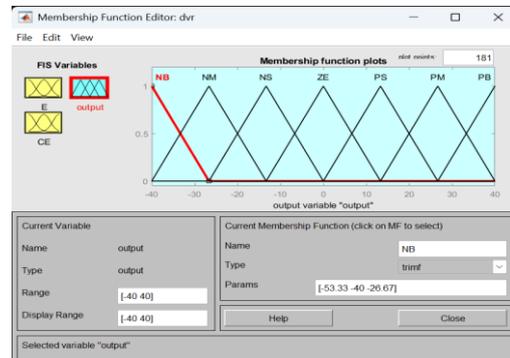
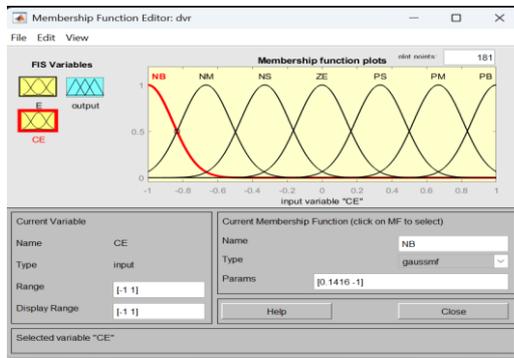


Fig:3.5 Input 2 from error and 1 output to the controller from the desire

Fig:3.6 Input 2 as an error checker

actual to tuned the output

to for pulse.

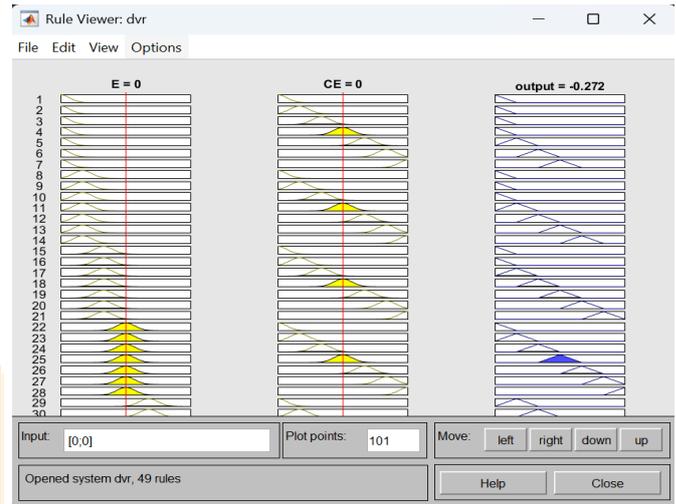
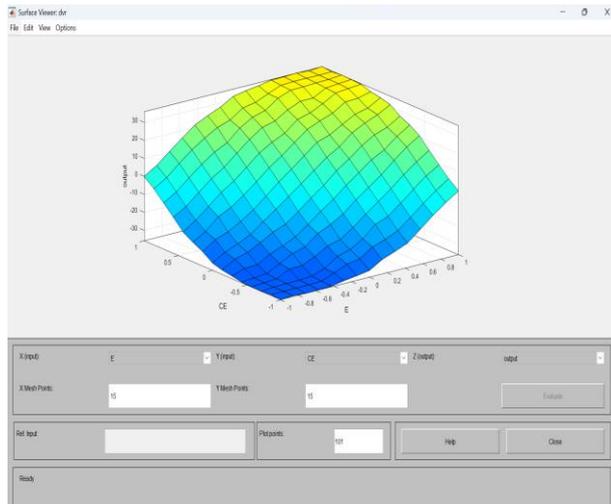


Fig:3.7 Surface view of the fuzzy logic of total 30 rules and its combination with input and output on the 3D graph & 30 different rules in visual and manual checking of what output will be determine with the input

IV. CONCLUSION

This paper represents simulation of DVR tuned with Fuzzy logic control. In order to show performance of DVR in mitigation of voltage fluctuations, Microgrid is simulated with MATLAB. A DVR is connected to the system through the series transformer which is tuned with FUZZY logic control. The simulation result shows that the fuzzy tuned with DVR rapidly compensates for the voltage sag/swell, ensuring improved power quality and reliability. Integrating fuzzy logic with a Dynamic Voltage Restorer (DVR) offers an adaptive and flexible approach to voltage sag compensation. By using fuzzy logic, the system can efficiently handle the uncertainty and complexity of voltage sag events, providing a more accurate and reliable solution to power quality issues. This is especially beneficial in systems where the voltage sags vary in depth, duration, and frequency, and traditional controllers might struggle to offer optimal performance.

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