Application of Dynamic Voltage Restorer through HHO Algorithm for Safe and Sustainable Operation of Electrical Distribution System

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Abstract. The voltage dynamic recovers steady-state, transient, and dynamic responses by protecting electrical equipment against unbalances, swells, and voltage sags and provides safe operation. The existing control structures were successful in restoring steady voltage. However, the intrinsic oscillations fail to account for those that may occur while quitting the system and introducing the DVR. The work describes a simple control system for dealing with dynamic, steady-state, and transient responses and intrinsic fluctuations that provides safety and sustainability as well. This suggested control system uses an upstream disturbance detection signal as the feed-forward. The feed-forward term is accomplished by the closed loop for the feedback of the controlling signal, which decreases transient changes and enhances system response. The HHO algorithm, the most recent metaheuristic optimisation algorithm, is utilised. Using MATLAB-Simulink, the system is simulated. Performance analysis of the proposed HHO algorithm is evaluated under different SWELL and SAG conditions.

1 Introduction

The paper aims to enhance the efficiency and effectiveness of the DVR in voltage compensation and power quality improvement. The issue of power reliability for loads is caused by SAG present in the source with AC power; this can be detected and compensated using DVR (Dynamic Voltage Restorer). In the below figure, the DVR operating principle is explained. In DVR, the transformer, IGBT converter, DC source and load are in series. Transformer provides power to SAG generated to give reliable AC.

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The widespread use of unbalanced power electronic equipment in factories, HVDC transmission networks, and huge furnaces will result in poor power quality (PQ). characteristics distinguish the possible power quality issues and are available in IEEE Standard 1159-2009 [1]. Voltage sag is one of the causes, and it significantly impacts power electronic devices [2],[3]. A dynamic voltage restorer is often recommended as compensation compared to other custom power devices (CPD) [4]. Due to voltage sag is illustrated. Significant problems were created in [5] and [6]. The impulsive load variations caused by induction motor switching are a crucial cause of voltage sag [7].

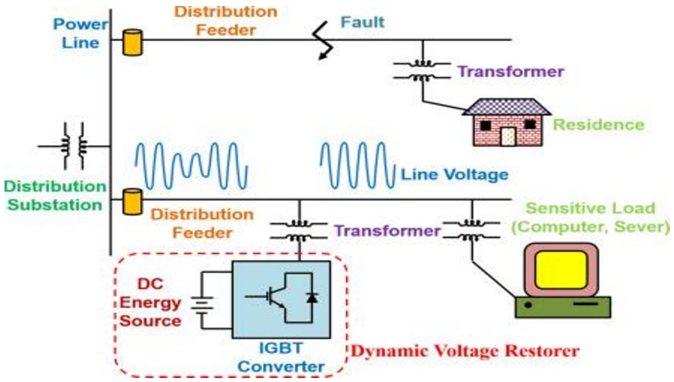

Fig. 1. Working Principle of DVR

The voltage swell and sag sources are infinite; we must cope with their influence on the system. Custom power devices (CPD) are devices used to improve power quality. Different CPD topologies are presented in [8]. Steady-state transient and dynamic reactions are critical to providing quality electricity to end consumers.

The widespread use of unbalanced power electronic equipment in manufacturing facilities, HVDC transmission networks, and large furnaces will result in poor PQ. These power quality issues have the potential to cause electronic equipment to fail. The open-loop approach was the most widely used in these tests because it enabled quick correction and had the disadvantage of settling errors and a significant time delay may impact the sustainable working of the equipment[9], [10].

Multi-feedback closed-loop [12] and single-feedback closed-loop [11] techniques were added to the DVR to improve the control system's performance. Voltage compensation was achieved in these studies, but there was no evidence of a transitory reaction. An ultra-capacitor combined with a higher-order controller will stabilise the dynamic response and improve the DVR [13].

Proportional resonant controllers were constructed in current and voltage control loops, with voltage compensation taking 20 milliseconds [14]. A multi-loop control technique is represented by a closed-loop method [15] to enhance the system's dynamic response to demand. The method must take the output's current derivative. That system outperforms earlier plans regarding steady-state, dynamic, and transient responses.

The voltage dynamic recovers steady-state, transient, and dynamic responses by protecting electrical equipment against unbalances, swells, and voltage sags. The existing Control structures were successful in restoring steady voltage. The work describes a simple control system for dealing with dynamic responses, steady-state responses, and transient and transient intrinsic fluctuations. This suggested control system uses an upstream disturbance detection signal as the feed-forward. The closed-loop feedback control signal accomplishes the feed-forward term, which decreases transient changes and enhances system response. The HHO algorithm, the most recent metaheuristic optimisation algorithm, picks distinct PI controller parameters. Using MATLAB or Simulink, the system is simulated. [1]

The ability of the grid to incorporate RES has an impact on the system's PQ. These sources need to be more trustworthy due to their irregularity. The DVR series compensator, used to examine harmonic analysis and voltage quality under the influence of RESs like wind farms and PV systems, is one of the most effective choices. DVR is used in this study to improve the PQ of the RESs. Two operating modes are addressed: on-grid and off-grid, with significant nonlinearity due to wind, PV, and loads. Two comparison research evaluations of numerous optimisation strategies and an additional controller are also presented to get the DVR's desired result and power. [2]

Loads and electric equipment are becoming more sensitive to power quality issues such as harmonics, imbalances, swell, and voltage sag as technology advances. A series compensator with a DVR is one of the best methods for protecting sensitive loads from voltage distortions and detecting faults. The primary goals of the DVR are to produce a control system that can adequately manage model uncertainties and disturbances, is stable, and is resistant. The UDE is provided to increase the DVR's ability to accurately change the load voltage in the face of a range of power quality concerns, notably those linked to grid voltage disturbances. In this study, a novel framework control technique is used. The Lyapunov stability theory is used to confirm and assess the stability of the proposed control system. The new control system has many advantages, including quick reaction, low tracking error, excellent harmonic rejection, streamlined design, durability, and sinusoidal reference tracking without specific frequency tuning or voltage conversions. The findings show strong performance and outstanding harmonic rejection when subjected to grid voltage perturbations. [3]

Transient, steady-state, and dynamic responses of the DVR constitute essential requirements for the ride-through capabilities of the DVR to safeguard sensitive loads against upstream voltage disturbances. DVRs also manage the transient oscillation when a DVR enters or exits. The DVR control system structure presented in this research is improved, optimised, and less complex. It can enhance dynamic, steady-state, and transient responses while removing inborn transient oscillations. The system response is greatly improved, and transient oscillations in the load voltage are eliminated by incorporating the feed-forward term. The Harris Hawks Optimisation (HHO) approach chooses the PI controller's parameters, a contemporary population-based optimisation method. According to the findings, the HHO provides the best system response. Simulink/MATLAB simulates the system, and the Typhoon HIL402 real-time emulator is used for validation. [4]

This study suggests a novel contribution in the form of an easy-to-use method for voltage control of a DVR. The recommended technique in a distribution network uses an error-driven PID controller to improve power quality performance in terms of voltage enhancement and bus stability, harmonic distortion reduction, and energy economy. This method maintains the load voltage close to or equal to the nominal value in the presence of various voltage disturbances, such as unbalanced and balanced power system harmonic distortion, fault conditions, notching, voltage imbalance, and sag/swell. For the recommended controller, a comparative performance analysis of four optimisation algorithms was conducted; it includes the Cuckoo search (CSA), Grey Wolf optimiser (GWO), Flower Pollination (FBA), and GOA. [5]

In this paper, a real-time control platform that has been developed for the change in PQ in a conveyance framework is shown. A voltage sag correction system for dynamic voltage restorers working with a VSI to improve PQ is demonstrated using a DSP-based control platform. Using the SPWM control approach to activate IGBTs, the output of the VSI is controlled. When a distribution system feeds a single-phase induction motor's sensitive load sags, a driver circuit and a filter circuit are built to correct for load voltage. A DSP processor, the TMS320F28027F, has been used to assert the developed control platform, and a few experiments have been conducted to demonstrate its efficacy[6].

2 PROPOSED METHOD

2.1 Electric Circuit Structure

The standard DVR power circuit configuration is described in Fig.2.. The DVR, situated between the common connection point and the load, is a series compensating device. DVR is a mixture of various electrical components like a three-phase electrical converter, DC supply, Active filter network, and series injection transformer.

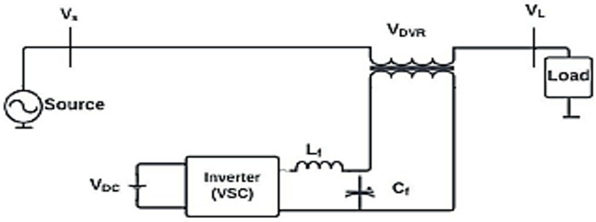

Fig. 2. Power circuit of the DVR system

2.2 Formation of Control System

2.2.1 Fundamental Circuit Structure

To compensate, the DVR control system must achieve several objectives, including Grid angle detection, which will match the DVR voltages to the PCC voltages.

2.2.2 The Planned Control Algorithm

All voltage disturbance at the voltage drop, at PCC, and load side across the internal impedance of DVR must be integrated into the control loop for adequate and quick dynamic responses. Given Fig. 3, the suggested control system principle.

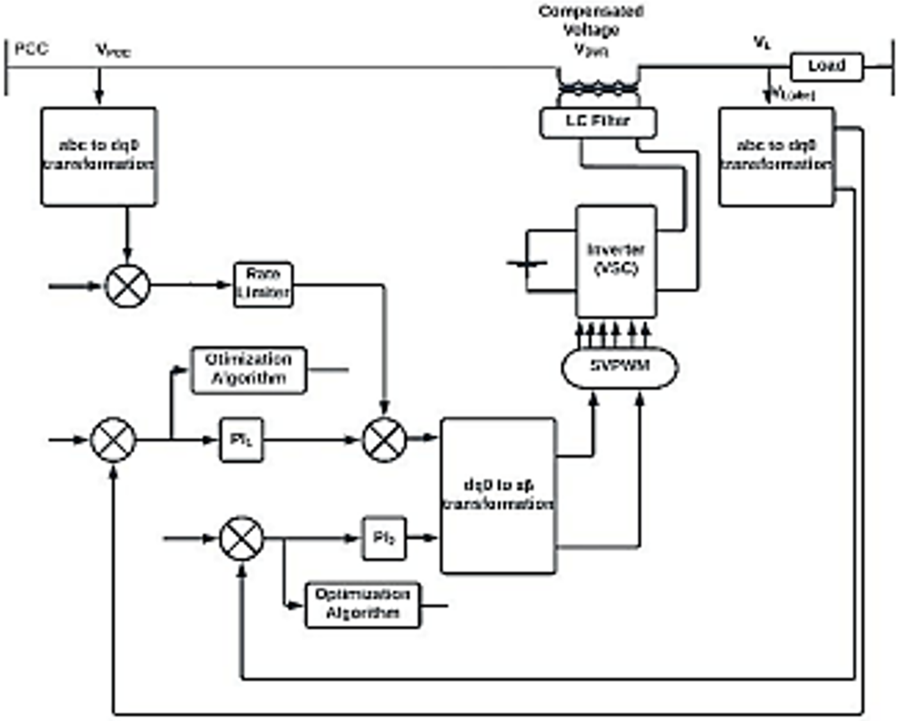

Fig. 3. DVR control scheme

The figure above shows the DVR control scheme with its working detail.

REGULATION OF CONTROLLER GAINS

Due to its inexpensive cost, modest structure, and high stability margin, PI controllers are a trivial regulator frequently used in commercial claims. The tuning of the PI controller, however, is the issue with the device.

$e_{vld} = V^*_{Ld} - V_{Ld}$ ……….. (1)

$e_{vlq} = V^*_{Lq} - V_{Lq}$ ………… (2)

$IATE_d = \int_0^{\infty} t|e_{vld}|dt$ ……….. (3)

$IATE_q = \int_0^{\infty} t|e_{vlq}|dt$ ……….. (4)

Where,

V* Lq - the disturbance-free counterpart of the load voltage's q-axis component,

V* Ld - the disturbance-free counterpart of the load voltage of the d-axis constituent,

VLq - the load voltage's true q-axis constituent,

VLd - the load voltage's true d-axis constituent.

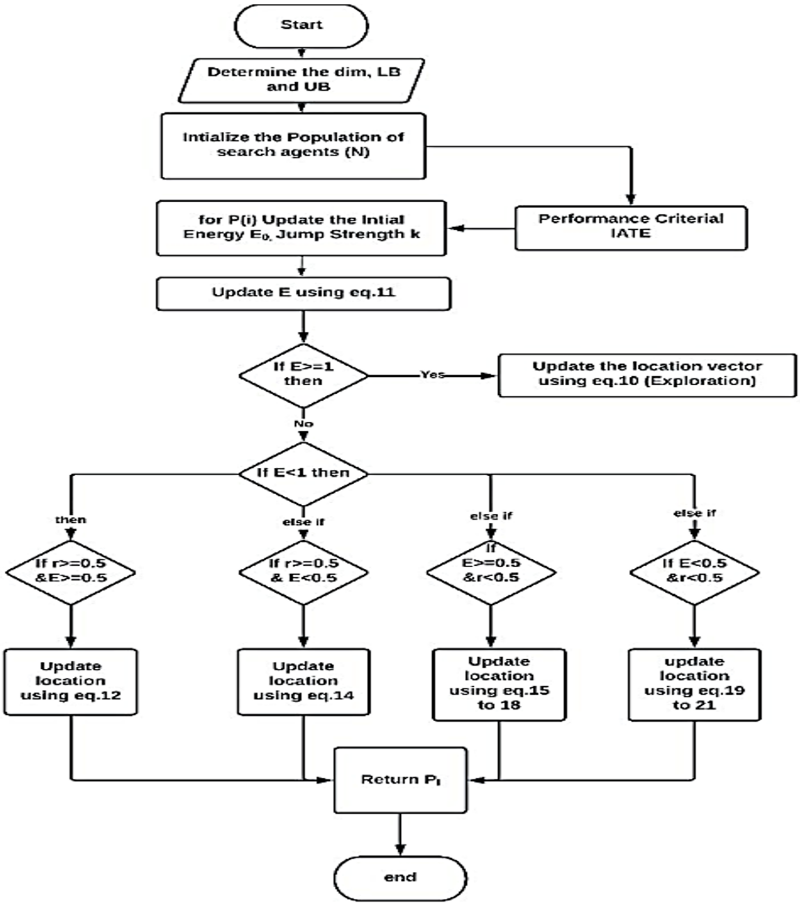

Fig. 4. Flowchart of Harris Hawks Optimization Algorithm

The Harris Hawks Optimisation (HHO) Algorithm, a metaheuristic optimisation technique, is used for selecting the PI controller's parameters since it provides the most suitable options. As shown in the above figure, thresholding conditions are used. The HHO algorithm represents a competent Harris Hawks rushing form's "surprise pounce" movement, using metaheuristic optimisation. The relationship between the suggested control system and Harris Hawks Optimisation is explained in the following section.

$$P_m = \frac{1}{N}\sum_{i=1}^{N} P_i(t) \ldots \ldots (5)$$

Where $P_i(t)$ shows each hawk repetition, the complete figure of the hawk is represented by N and t.
The energy of the rabbit is shown below,

$$E = 2\,E_0\left(1 - \frac{t}{T}\right) \ldots.(6)$$

$E0$ is the original energy state, T is the iteration's max value, and E specifies the target energy.

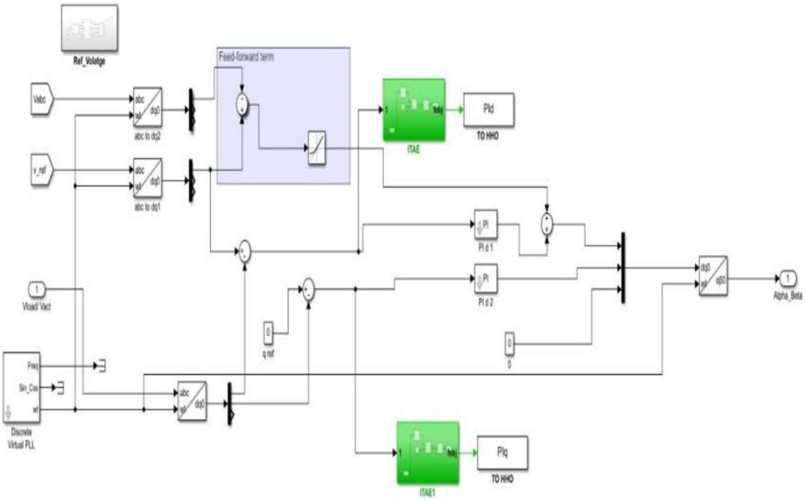

Fig. 5. Simulation of the Proposed Control System in MATLAB/Simulink

The simulation circuit of the proposed model in Simulink is shown in the above figure using the HHO algorithm.

3 RESULT

The proposed model of DVR using the HHO algorithm is analysed under different SAG and SWELL conditions. This model is designed and analysed using Matlab-Simulink programming.

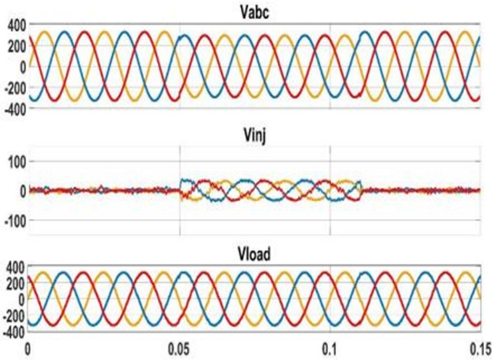

Fig. 6. Supply, Inject and Load Voltage waveforms for 10% sag

A Sag of 10% in supply voltage is created by initiating an LLLG fault in the line. A fault is initiated at 0.05ms and cleared at 0.10ms. The fault resistance to create a 10% sag in phase voltage is 0.018 ohms. Fig shows that the source voltage is reduced to 90% of its rated voltage (V_{abc}) of 294V. For the same fault duration, DVR injects the required voltage (V_{DVR}) of 32.6V to keep the load voltage ($_{Vload)}$ constant at 326.6V.

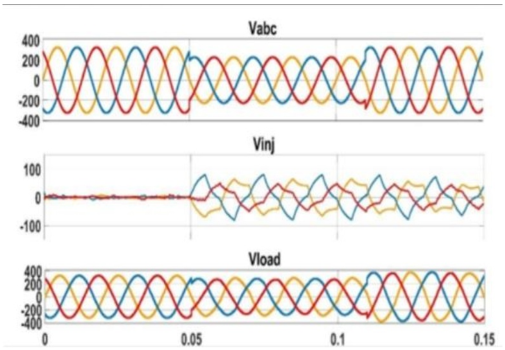

Fig. 7. Supply, Injected and Load Voltage waveforms for 30% sag

A Sag of 30% in supply voltage is created by initiating an LLLG fault in the line. The fault is initiated at 0.05ms and cleared at 0.10ms. The fault resistance used to create a 30% sag in phase voltage is 0.032 ohms. The fig shows that the source voltage is reduced to 70% of its rated voltage (V_{abc}) of 228.62 V. For the same fault duration DVR injects the required voltage (V_{DVR}) of 97.98V to keep the load voltage ($_{Vload)}$ constant at 326.6V.

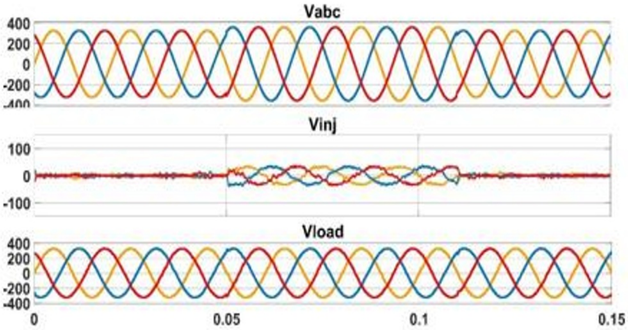

Fig. 8. Supply, Injected and Load Voltage waveforms for 10% swell

The swell of 10% in supply voltage is created by using a programmable voltage source block. Practically it can be realised by suddenly switching off large machines, power surges and lightning. Swell is initiated at 0.05ms and cleared at 0.10ms. Fig shows that the source voltage is increased to 110% of its rated voltage (V_{abc}) of 359.26V. DVR absorbs the required voltage (V_{DVR}) of 32.6V for the same fault duration to keep the load voltage ($_{Vload)}$ constant at 326.6V.

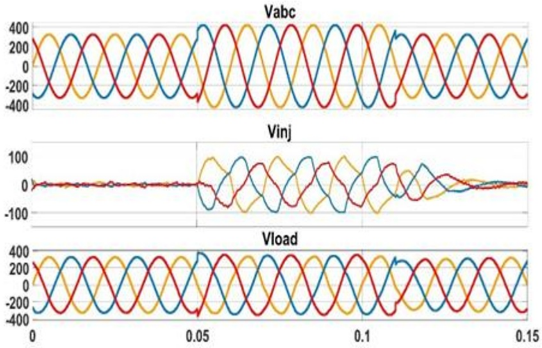

Fig. 9. Supply, Injected and Load Voltage waveforms for 30% swell

The swell of 30% in supply voltage is created using a programmable voltage source block. Practically it can be realised by suddenly switching off large machines, power surges and lightning. Swell is initiated at 0.05ms and cleared at 0.10ms. Fig shows that the source voltage is increased to 130% of its rated voltage (V_{abc}) of 228.8V. For the same fault duration, DVR absorbs the required voltage (V_{DVR}) of 97.98V to keep the load voltage ($_{Vload)}$ constant at 326.6V.

4 Conclusion

For the dynamic voltage restorer (DVR), this work developed a simple and advanced control strategy that provides an excellent safeguard against load voltage unbalances such as swells and sags and thereby gives a sustainable working of the equipment. The combination of closed-loop feedback management signals and feed-forward upstream detection substantially aids in cultivating momentary reactions and removing undesired transitory oscillations during DVR compensation. The Harris Hawks Optimisation algorithm was developed to support calibrating PI parameters to provide optimal PI limits. It significantly dampened the intrinsic voltage oscillations during fault conditions and ensures the safe and sustainable working of the electrical distribution system.

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