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VOLTAGE SAG MITIGATION USING LEVENBERG MARQUARDT ARTIFICIAL NEURAL NETWORK BASED DYNAMIC VOLTAGE RESTORER

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ABSTRACT

Nowadays the problem of power quality has grown to be a significant concern in order to preserve the quality of supply. The moderngeneration relies heavily on electrical energy toenhance their quality of life. Electricity is necessaryfor the operation of modern devices like computersand electric motors. Power quality is a crucial problemin today's power system that can affect both utilities andconsumers. High-quality supply is necessary for the equipment to function better. Voltage sag/swell is one of the most common power quality issues in transmission networks. To lessen such issues, thereare a lot of contemporary custom devices. TheDynamic Voltage Restorer (DVR) is the most economical and efficient of them .The Distribution Flexible AC Transmission System (D-FACTS) can be equipped with a DVR to address issues related to irregular voltage, current, or frequency in the distribution grid. A summary of DVR and its control scheme, which is used to mitigate power quality issues, is presented and properly analysed in this paper. Artificial neural network has been used in the controller which givessignal to the system. Artificial neural network based DVR is used to ease the sag problem.

Keywords:– Dynamic Voltage Restorer (DVR) , Artificial Neural Network , PI Controller , VoltageSag

I. INTRODUCTION

Sagging voltages in power distribution systems are currently one of the primary challenges with power quality. A voltage sag is a transient spike that can lasta number of cycles or a few seconds in the rms ac voltage at the power frequency (0.1-0.9 p.u. of the voltage specified). The majority of voltage drops are brought on by remote faults on the power distributionsystem, such as single-, double-, and three-phase faults[1].

Problems with power quality have recently caused industries to lose a great deal of money and time. As a result, there is a constant need for high power quality, which helps to lessen issues with power quality such harmonic distortion, voltage sag, flicker, and interruptions. Because practically all industrial processes are becoming increasingly heavily automated, it is especially crucial to prevent such phenomena. Because power supply failures brought on by these disturbances typically have a significant impact on production costs, high quality is required. There are several ways to get around voltage sags. One approach is to combine energy storage with dynamic voltage restorers. The dynamic capability to make up for voltage drops on critical loads is possessed by a power electronics device known as theDVR. The DVR maintains a steady load voltage and restores a voltage waveform by injecting the proper voltage. Injection transformers, passive filters, voltage source converters (VSC), and lead acid batteries forenergy storage make up the DVR [1][2].The lead acid battery-powered Dynamic Voltage Restorer is an exquisite and affordable way to provide better dynamic voltage compensation capability than shunt-connected devices. The distribution system is connected in series with the DVR, a specialized power device. Through the injection of three-phase output voltages that are controllable in terms of magnitude,phase, and frequency, MOSFETs are utilized by the DVR to maintain the load's voltage [2].

Using DVR is one cost-effective method to lessen sensitive load voltage sags and swells. The ANN controller is accustomed to address the drawbacks of the present approach**.** The ANN control system is used in the design and simulation of DVRs in order to enhance power quality [4].

The DVR can be used as a voltage distortion compensator with ANN to mitigate harmonics and voltage sag/swell generated with zero sequence components, as well as a voltage sag restorer by using a delta connected transformer between the power source and buffer transformer. ANNs, which are networks of different nodes that function as neurons and are arrangedin layers, resemble animal brains in general. Each node forwards information to the next node after completing the required steps after receiving it. Every layer processesany input to produce an output [7].

II. BASIC CONCEPTS OF DYNAMIC VOLTAGE RESTORER (DVR) AND ITS PRINCIPLES

An injection transformer bank, an IGBT or aMOSFET, and a bank of capacitors for storage of energy comprise a DVR, a solid state power electronics switching device. It is connected to the distribution of the system and the load shown in the given Figure 1 in series. Utilizing an injecting transformer to deliver a controlled voltage produced by a forced commuted transducer is connected inseries with the bus voltage is the DVR's primary function [3].

This voltage is controlled by a DC to AC inverter usinga sinusoidal PWM technique. The DVR only injects a small amount of voltage during regular operation to make up for device losses and the injection transformer's voltage drop. But when distribution system voltage sags, through the injection of a regulated voltage paired with a specific magnitude as well as phase angle into the distribution framework atthe crucial heap , the DVR controller determines and creates the necessary voltage to keep the voltage that is supplied to the load constant. [5].

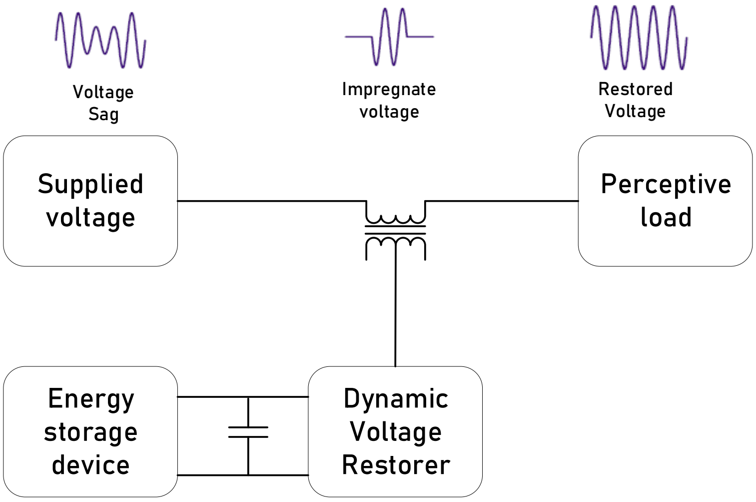

Fig. 1: Basic Topology of DVR.

In order to protect the loads from these issues with power reliability, the DVR perceives and fixes voltagedips in the AC power source. The DVR is made up ofthe injection transformer, IGBT converter, and DC power sources that are coupled in series with thesensible load and the power line. Batteries, flywheels,super capacitors, and superconducting magnetic storage units are examples of DC power origin that canbe utilized. If a specific distribution feeder lines has afault, it could cause a sag in the input AC power line voltage to spread throughout the power grid. Using anIGBT converter, the DVR utilizes the DC power source to generate AC power after sensing sag. For thepurpose of correcting the sag and offering the sensitive load with a fresh supply of highly dependable AC power,the transformer feeds the generated power to the line. Adevice called a dynamic voltage restorer (DVR) can be employed in distribution networks to fix short voltage reductions, also known as voltage sags, by injectingthree-phase voltage in series and synchronism with the distribution feeder voltages. DVR systems can infuse as much as 50% of the nominal voltage, still only for apeak of 0.1 seconds. This is not a major problem becausethe majority of voltage sags are substantially less than 50%. [1][6].

2.1Basic Configuration of DVR :

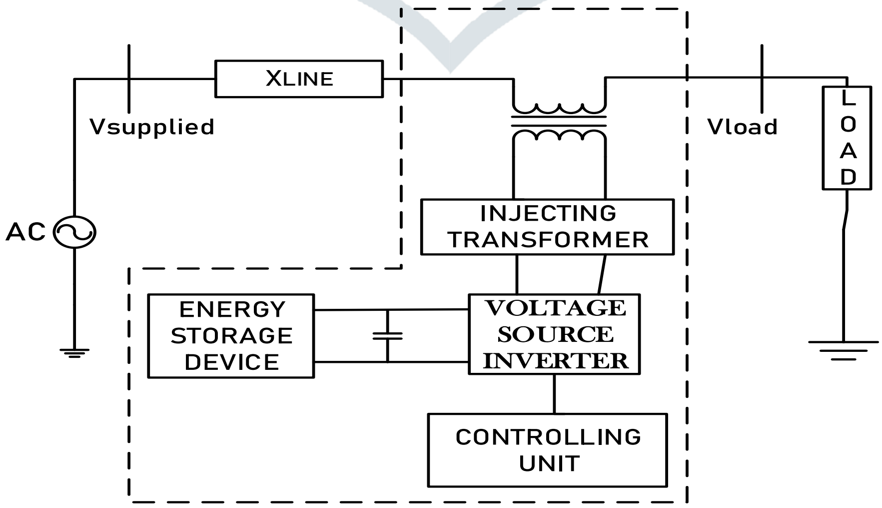

Fig. 2: Basic Structure of DVR

The basic framework of the DVR shown in the Fig. 2contains the following blocks:

1. Voltage Source Inverter
2. Injecting transformer
3. Passive Strainer
4. Energy Storage Device
5. Controlling Circuit

1. Voltage Source Inverter-

The variable supply voltage (VSI) modifies the stored fixed supply voltage. Through the transformer, the converted voltage is increased. Due to the use of a step- up injecting transformer, the grade is typically low voltage and large current. The voltage at which VSI outputs should be:

a) Symmetrical and clean sinusoidal
b) Identical to the system's phase sequence
c) Desirable magnitude
d) For precise time span
e) Should be quick

2. Injecting Transformer-

An injecting transformer raises the AC voltage delivered by Voltage source inverter to the necessarylevel. The step down transformer linked with the distribution line determines how the injection transformer is wound. Either a delta/open star winding or an in star/open star winding interconnection is made. While the latter connection prohibits it, theformer relation permits the injection of zero sequence elements as well. The rating of the inverter and injection transformer determines how much voltage sag or swell compensation is provided by DVR. Using the power computation equation and the secure margin denoted by Ks, the MVA rating is determined. The injection transformer's primary voltage (Va) andprimary current rating (Ia) are respectively.

$$P = Ks\,(Va)(Ia) \qquad (1)$$

The rating of the injecting transformer can be calculated by –

$$V_{in} = D_e Vr \qquad (2)$$

$$V_s = (1 - D_e)Vr \qquad (3)$$

The injection voltage is Vin, the maximum singlephase voltage sag that needs to be compensated (De<I)is De, and Vr is the rated rms voltage of the primary feeder.

3. Passive Strainer-

It eliminates the harmonics existing in the VSI's output. It can be maintained at the transformer's HV side or the inverter side. By preventing switching harmonics from entering the injection transformer, a filter installed at the inverter side can lessen the ratingand voltage stress applied to the transformer. Therating of the transformer improves if the filter is positioned on the injection transformer's HV side,where harmonics may enter.

4. Energy Storage Device-

This device delivers the actual power needed to createthe compensating voltage during compensation. DC capacitors, super capacitors, flywheels, and lead acid batteries are examples of energy storage devices. The DVR's capability to compensate is greatly impacted byits capacity. A real power compensation system is needed for the system with the large disturbance. Batteries need to be converted from DC to AC, but flywheels need to convert from AC to AC.

5. Controlling Circuit-

The control circuit examines the system steadily. By matching the source voltage to the reference voltage, it can detect any system disturbances. It utilizes this information to produce switching command signals for the VSI, which allow the DVR to compensate for the generating voltage.

2.2 Basic Principle of DVR:

The prime function of the DVR is to infuse a voltage of the required magnitude and frequency in order to get back the load side voltage to the intended amplitude andwaveform even in the event that the source voltage is distorted or imbalanced. Solid state power electronicswitches identified as gate turn off thyristors (GTOs) are frequently employed in pulse width modulated (PWM) inverter structures. At the load side, real and reactive powercan be independently controlled by the DVR or it can absorb it. Put differently, the dynamic voltage restorer consists of a solid-state DC to AC switching power converter that injects aseries of three-phase AC output signals. [2].

- A DVR protects the load's voltage from variations. Let the three phase voltage phasors, Va1, Vb1, and Vc1, operate normally. The phase voltage vectors may be changed to Va2, Vb2, and Vc2 under anomalous circumstances. Under steady state conditions, DVR doesn't provide any actual power.
- DVR doesn't do anything when things are normal; it only works when something unusual happens. DVR can both supply and absorb active and reactive powerwhile it is operating. A dynamic voltage restorerrectifies the voltage of the load by providing reactivepower that is internally generated when a minor faultoccurs. When active power is needed to balance moresignificant faults, DVR generates it. To generate active power, a DC energy device is needed.
- A series controller linked in series with the load is called a dynamic voltage restorer (DVR). To put back the load voltage to its pre-abnormal state, the injecting transformer affects the source voltage by including the appropriate voltage vector (magnitude and angle.)

2.3 Modes of Operation of DVR:

Using a dynamic control voltage, a dynamic voltagerestorer connects a pulse width modulation inverter that is attached in series with the bus voltage. The following illustrates a DVR's three modes of operation:

i. Protection Mode

ii. Standby Mode

iii. Injection Mode

Protection Mode-

There are bypass switches to separate the DVR from thesystem in the event of an overload current from a short circuit or a large inrush current. An alternative pathway is used to supply the system with current. If there is a short circuit on the load or a significant inrush current, the Dynamic voltage restorer will be disconnected from the network by using the bypass switches, and the first switch will be closed to provide the load current with an alternative path.

Standby Mode-

The low voltage winding of the injecting transformer is shorted in this mode. Switching operations are absent in this mode. When the booster transformer is in standby mode, the converter shorts the low-voltagewinding of the booster transformer. In this mode of operation, the transformer primary will receive the full loadcurrent without any semiconductor switching.

Injection Mode-

Using an injection transformer, the DVR applies the compensating voltage in this mode. The DVR detects a disturbance in the supply voltage and, in the injection/boostmode, injects a compensating voltage through the booster transformer.

The device voltage restorer's injected voltage can be expressed as follows:

$$V_{inj} = V_{load} + V_s \tag{4}$$

Where,

V_{load} = Desired magnitude of the load voltage.

V_s = Supply voltage during Sag.

2.4 Compensation Techniques of DVR:

Different voltage sags and swells, different load conditions, and DVR ratings all affect voltage injection or compensation techniques. To account for voltage sag and swell, three distinct DVR voltage injection techniques are offered. These are listed in the following order:

1. Pre-Sag Compensation Technique

2. In-Phase Compensation Technique

3. Phase Advanced Compensation Technique

1. Pre-Sag Compensation Technique

In this method, the Dynamic voltage restorer continuously observes the source voltage. The DVR supplies the system with the voltage that is absent within the pre-sag and during-sag voltage injections. Both magnitude and angle must be compensated for by DVR during the process. While the load voltage can ideally be restored, the injected power cannot be controlled inthis method. The amount of power injected depends on the fault type and load conditions [2].

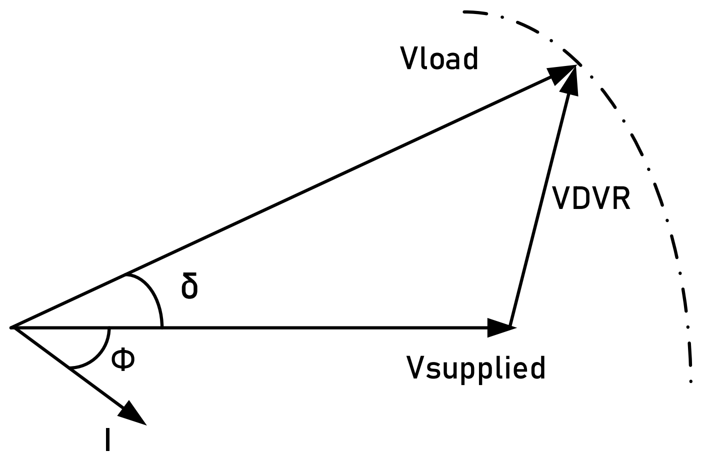

Fig. 3: Vector representation of pre-sag compensatory.

1. In-Phase Compensation Technique

In this type of method, neither the load current nor the pre-fault voltage influences the infused voltage. Both the injected voltage and the source voltage are always in phase. The injected voltage magnitude is minimized when the load voltage magnitude stays constant, which is an added advantage of this method. Although the pre-fault voltage and the load voltage have the same magnitude, their phase angles differ. The supply and load voltages have the same phase angle and are equal under normal circumstances. Phase angle jumps occur when the magnitude of theload voltage is reduced under anomalous conditions such as sag. The DVR makes up for both parameters [2].

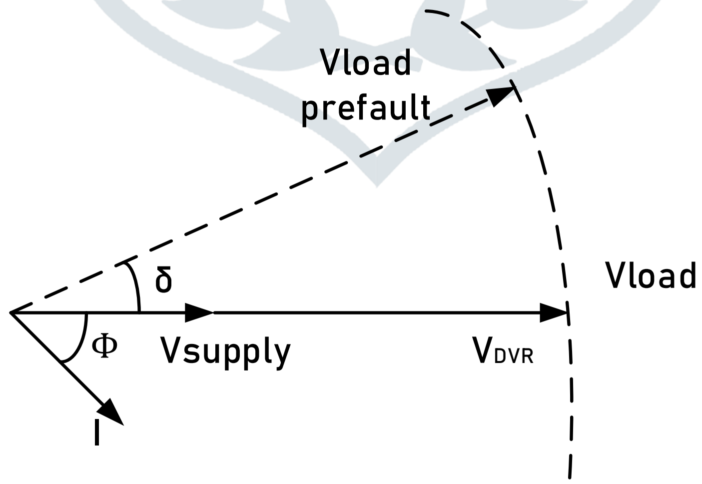

Fig. 4: Vector diagram of in-phase compensation

2. Phase Advanced Compensation Technique

Since phase advance methods only involve the injection of reactive power rather than active power, they outperform other methods in this regard. By injecting compensating voltage perpendicular to the load current, the injected active power is reduced to zero. Compared to the pre-sag or in-phase methods, the phase-advance method's injected voltage is higher [2].

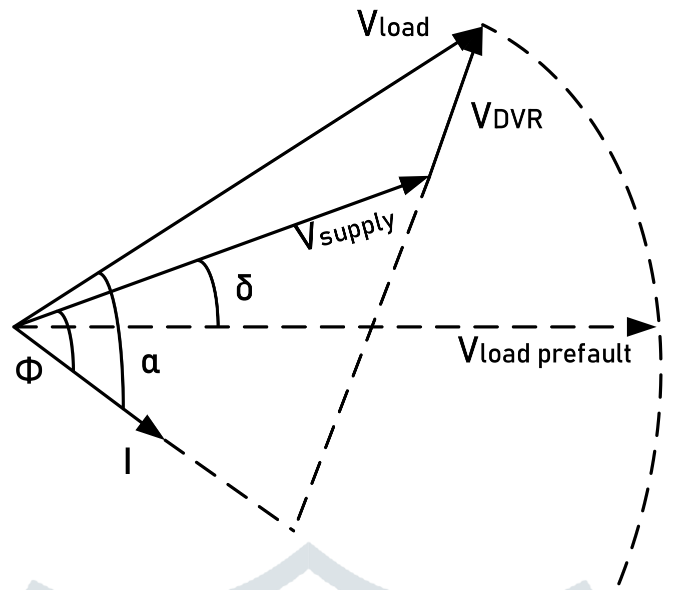

Fig. 5: Vector diagram of phase advance compensation

III. ARTIFICIAL NEURAL NETWORK

The controller's main goals are a highly engaged reaction to the planned DVR recompense and fast, extremely accurate detection of the disruptive signal. The conventional controller cannot function properly in the presence of parameter changes, load disturbances, non-linearity, etc. According to a recent survey, an ANN-based controller maintains the DVR stable under a variety of operating conditions and offers quick dynamic responses [4].

The interconnected neurons that make up the nonlinear elements of the ANN are called neurons. Usually, it depicts a collection of linked, extremely basic nonlinear components with the ability to change and grow. Neural networks are characterised primarily by their topology, communication style with their surroundings, training methodology, and information processing power [7] [9].

To optimise the DVR's performance attributes, a multi-layer neural network-based control system is created. Three layers make up the ANN-based controller: a single neuron in the input layer, twenty neurons in the hidden layer, and one neuron in the output layer. The offline neural network controller training uses the PI controller data, which are kept in the MATLAB workspace. [8].

The compensation performance of the ANN controller is determined by development and input. The chosen configuration consists of two inputs along with an output for the dc link voltage, the measured dc link voltage, with the PI controller reference signal. A reference signal has to be received in order received signal to a hysteresis control [9].

3.1 Types of Artificial Neural Network (ANN) :

Neural Networks are machine learning networks that function similarly to the nervous system in humans. It is intended to operate similarly to the human brain, which has numerous interconnected components. Artificial

Neural Networks are widely used in domains where conventional computers perform poorly. The computational model uses a variety of artificial neural network types and some of them are:

1. Kohonen Self Organizing Map (KSOM)
2. Radial Basis function Neural Network (RBFN)

1. Kohonen Self Organizing Map Neural Network.

In this neural network, vector from any number of dimensions are fed into a separate map. Training data for an organization is generated by training the map. The map might be two or one dimensional. The neurons' weight can change according to the value.

A fixed neural location will be maintained throughout the map's training process. Every value of a neuron is given a tiny amount of weight and an input vector at the start of the self-organization process. A neuron is the winner when it is nearest to the point. More neurons will start shifting in that direction in this second phase when the winning neuron gets closer to the point. Neurons and a point's distance are measured using Euclidean distance. The neuron that has the shortest distance will be the winner.

Every type of cluster is represented by a neuron, and iterations will result in the clustering of all points. Data pattern recognition is one of the primary uses of Kohonen Neural Networks. Additionally, it is employed in medical analysis to more accurately classify diseases. After the trends in the data are analyzed, the data are clustered into several categories.

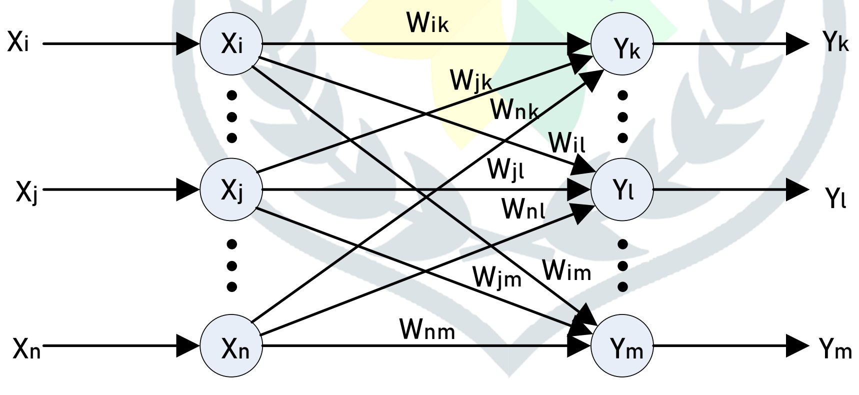

Fig. 6: Kohonen self-organizing feature map architecture

2. Radial Basis function Neural Network (RBFN)

For function approximation problems, one specific kind of artificial neural network is called a Radial Basis Function (RBF) network. RBF Networks have a three-layer architecture, a universal approximation, and a faster learning rate than other neural networks.

Neural networks are made up of three layers: the hidden layer, the output layer, and the input layer. Compared to most neural network architectures, which have multiple layers and repeatedly apply nonlinear activation functions in order to achieve nonlinearity, this arrangement is essentially different. After being accepted by the input layer, data is transmitted to the hidden layer for computation. The most potent and distinctive feature of the Radial Basis Functions Neural Network is its hidden layer, which sets it apart from other neural networks. Regression and classification are examples of prediction tasks that belong in the output layer. Such a function has a positive response for all values of y, which decreases to 0 as |y|→0. Generally speaking, the Gaussian function is defined as follows:

$$f(y) = e^{-y^2} \quad (5)$$

The following equation provides the derivative of this function:

$$f'(y) = -2ye^{-y^2} = -2yf(y) \quad (6)$$

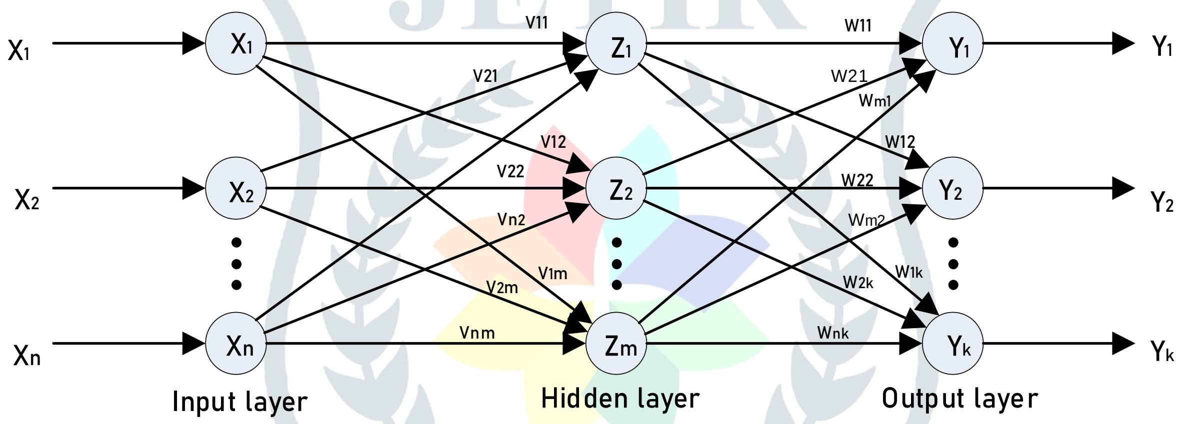

Fig. 7: Architecture of (RBFN)

A (RBFN) is a function with real values whose value only depends on how far away the origin is. While we use other types of radial basis functions as well, a Gaussian function is the most commonly used one. In the case with several predictor variables, the Radial Basis Functions Neural Network has an equal number of dimensions as variables. The best-predicted value of the new point can be neuron processed.

3.2 Training Algorithms :

In a neural network, the learning process is coordinated by the training algorithms, and the model's parameters are adjusted during training by the optimisation algorithm, also known as the optimizer. Numerous variations exist among optimisation algorithms. In this paper two training algorithms are used.

1. Function Fitting Neural Network
2. Levenberg-Marquardt Algorithm

Function Fitting Neural Network

Training a neural network with a set of inputs to generate a set of target outputs that are associated with the inputs is known as function fitting neural network. After the network is constructed with the liked hidden layers and training algorithm, it's necessary to be trained using a set of training data. After fitting the information, the neural network creates a generalization of the input-output relationship. Subsequently, the trained network can produce outputs for inputs that it was not trained on.

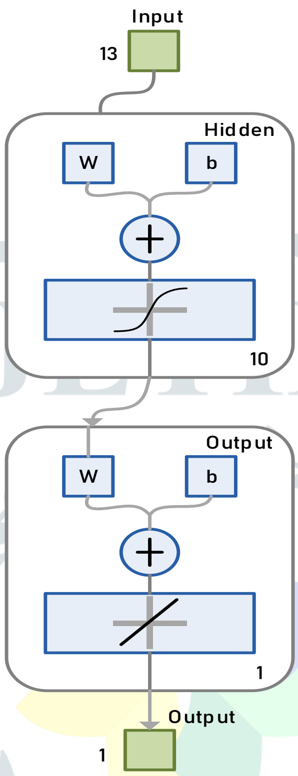

Fig. 8: Function Fitting Neural Network

Levenberg-Marquardt Algorithm

The Levenberg-Marquardt algorithm demonstrates stable convergence as well as speed during neural network training. Two other popular methods for neural network training are the Gauss–Newton algorithm and the steepest algorithm descent, which is also known as backpropagation error. The Gauss-Newton algorithm is used for speed by the Levenberg-Marquardt algorithm, while the steepest descent method is used for stable results. The Levenberg-Marquardt algorithm's main goal is to train a combined process around an area with a complex curvature. The steepest descent algorithm is used by the Levenberg–Marquardt algorithm until the curvature is precisely correct to make a quadratic approach. To drastically accelerate its convergence, the Gauss-Newton algorithm replaces the Levenberg-Marquardt algorithm.

The Levenberg-Marquardt Algorithm is presented by the equation,

$$w_{k+1} = w_k - (J_k^T J_k + \mu I)^{-1} J_k e_k \quad (7)$$

IV. SIMULATION RESULTS AND DISCUSSIONS

Figure 6 shows the Simulink model of the DVR connected system that was created in the MATLAB/Simulink software using the sim power system toolbox. The three-phase load is linked to the three-phase ac voltage source through a DVR to enhance voltage performance.

A control method, injection transformer, capacitor, ac filter, and a three-phase inverter module make up a DVR. PWM switching has been utilized in the three-level voltage source inverter to control the electronic valves. The amount of energy needed to be supplied by the capacitor, or energy storage device, is ascertained using the battery on the DC side.

As shown in the simulation diagram a ANN based controller is used for controlling the IGBT based universal bridge. The output of the ANN controller is given to discrete PWM generator (mask) in orderto send the controlling pulses to the DVR.

Three-phase programmable Voltage Source (Mask Link) is used as a source for the distribution grid. A zero-impedance, three-phase voltage source is implemented by this block. Through the block's input 1(N), the three sources' common node (neutral) is reachable.

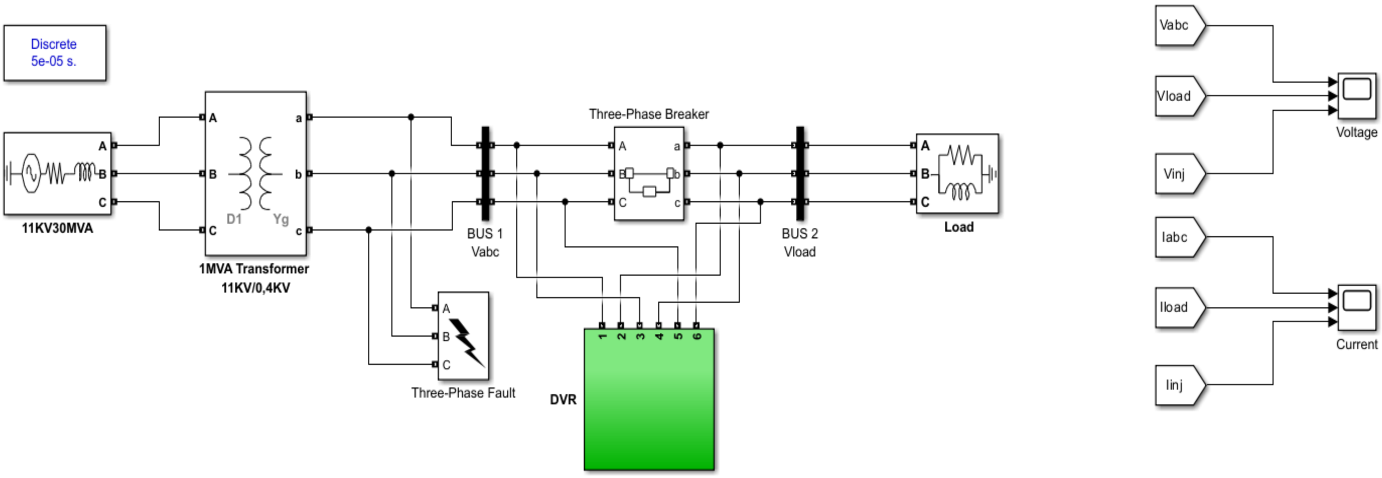

Fig. 9: Simulation System

It is possible to pre-program the fundamental's amplitude, phase, and frequency variations in time. Furthermore, the fundamental can have two harmonics superimposed on it.

Implementing a two-level converter makes use of the switching function technique. The converter is modeled as a switching function that is either controlled by pulses produced by a PWM generator (0/1 signals) or by pulses averaged over a predefined duration (PWM averaging: signals between 0 and 1).

Park and Inverse park transformations, which are techniques used in control systems to convert three- phase ABC (alpha, beta, and gamma) quantities to DQ (direct and quadrature) quantities, specifically DQ0 (direct, quadrature, and zero).

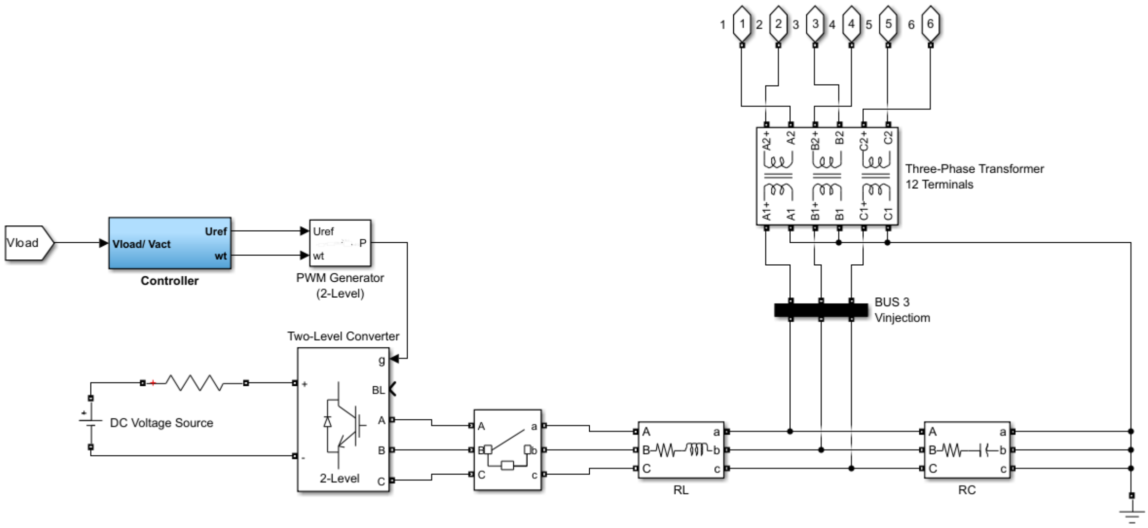

Fig. 10: MATLAB / Simulink Model of DVR

This explains the significance of thesetransformations in simplifying control of systems by converting AC quantities to DC quantities foreasier control. The demonstration the implementation of these transformations using MATLAB Simulink, generating Three-phase sine waves and visualizing the transformation outputsthrough scopes. Additionally, the presenter discusses the inverse transformations, showing how to revert from DQ0 back to ABC. The applications of these transformations in inverter control logic and motor control logic are highlighted, emphasizing their importance in tuning and controlling systems.

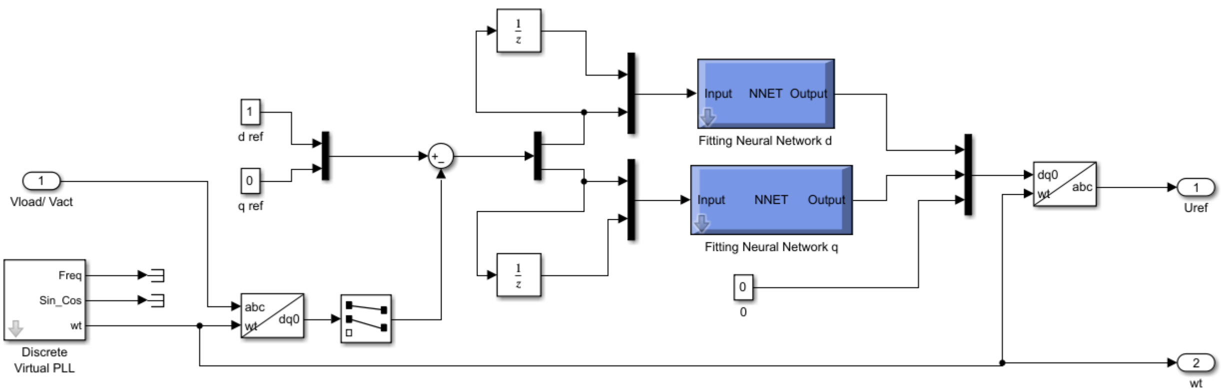

Fig. 11: Control system of DVR consisting Fitting Neural Network.

Voltage sag can be caused by the abrupt disconnecting of a load, malfunctions within the system, or Voltage sags in a power system can sometimes referred to as dips in voltage or voltage reductions .when there is a temporary and short-duration decrease in the voltage level. The starting of large motors, especially in industrial settings, can cause a significant current draw. This sudden demand for current can lead to a voltage sag in the system. Switching operations, such as opening or closing circuit breakers, can cause voltage sags. This is because the sudden change in the system's configuration can affect the voltage level.

Due to network faults, the system experiences voltage imbalance for a specific amount of time. At this time, there is a voltage interruption at the PCC (Point of Coupling), and the DVR works to maintain and restore the voltage profile. In this case, all voltages are measured in terms of unit values, and any disturbance is shown to cause an increase in the magnitude voltage profile over its rated value. To make up for this dip in voltage, the DVR runs and injects the desired voltage. Because compensating voltage is added during this time, there is a small disturbance at the starting and ending of the sag after compensation.

The DVR control system typically operates in a rotating reference frame (dq frame) using the Park transformation. This allows for effective control in the presence of varying voltages. The waveform of source voltage (Vabc) and Load Voltage (Vload) of the simulation is shown in fig.12 and fig. 14 respectively. The compensating Voltage or injection voltage (Vinj) introduced byinjecting transformer of DVR is shown in fig. 13.

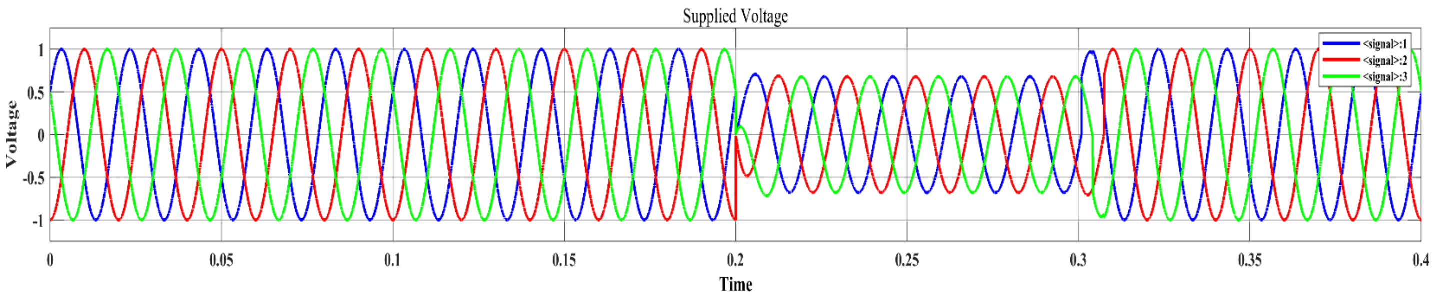

Fig. 12: Waveform of Source Voltage (Vabc)

When a voltage sag is detected, the DVR infuse the compensating voltage into the system. This compensating voltage is designed to be in phase and amplitude with the sagging voltage, effectively restoring the voltageto its nominal level.

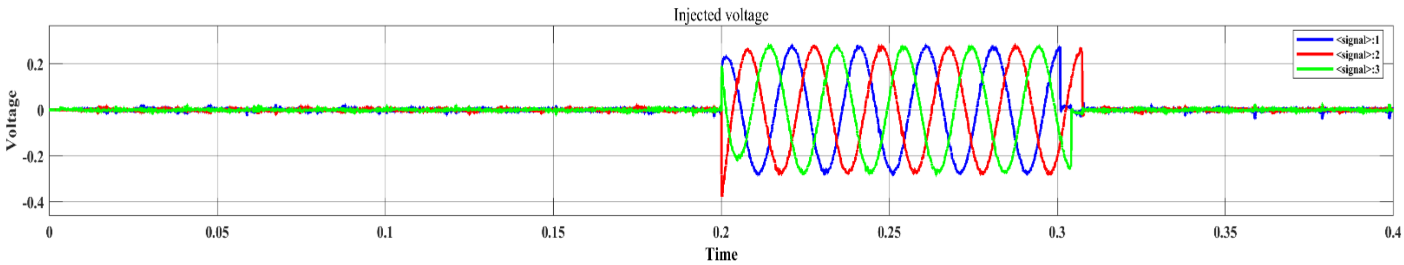

Fig. 13 : Waveform of Injected Voltage (Vinj)

The DVR is designed to isolate itself from the power system during normal operating conditions. It only connects to the system when a voltage sag is detected, minimizing its impact on the system during normal operation. DVRs can be customized based on the specific requirements of the connected loads. This ensures that the compensating voltage provided by the DVR is tailored to the needs of the critical equipment.

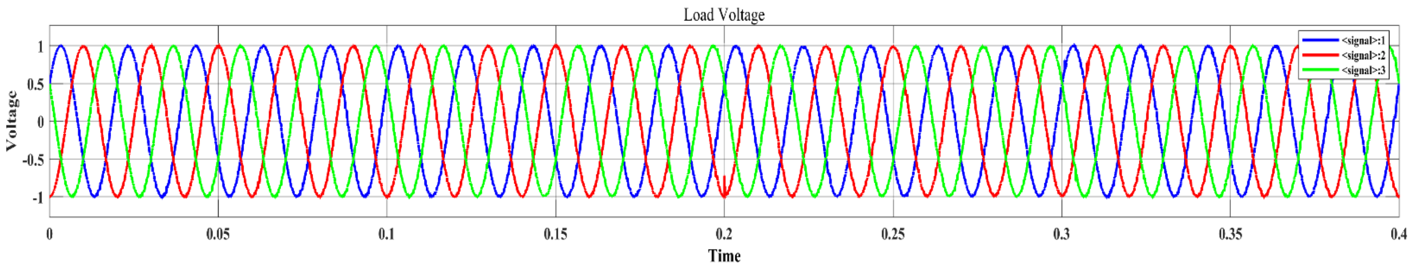

Fig. 14: Waveform of Load Voltage (V load)

One of the key advantages of DVRs is their ability to respond quickly to voltage sags, typically within a few milliseconds. This fast response time is crucial for ensuring that sensitive equipment is protected from the effects of voltage sags.

Using a DVR for voltage sag mitigation helps maintain power quality, preventing disruptions to sensitive electronic equipment. It is a targeted and effective solution for addressing short-term voltage variations in power distribution systems.

V. CONCLUSION

An extensive analysis of DVR performance has been provided in this paper. The aforementioned research demonstrates that the DVR is appropriate for voltage sag compensation through the use of an Artificial Neural Network control system, which consists of a Fitting Neural Network technique. DVR may function with lower costs, smaller dimensions, and a quicker dynamic response to disturbances caused by power quality problems, according to these discussion papers. Utilizing the data from this study, scientists can develop a new DVR design that is more adept at managing voltage fluctuations in electrical systems. The findings of this study on DVR applications indicate that trends in DVR usage over time are still thought to be a rich area for research.

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