Emergency Control in Distribution System using Anfis Based Dynamic Voltage Restorer

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***Abstract*: Dynamic voltage restorer is a modern device that is used to protect the consumers from sudden voltage amplitude changes occurs in the distribution system. The control strategy of multifunctional DVR was proposed in distribution systems for emergency control. The steady state error was eliminated and transient response was improved in DVR by using Posicast and Adaptive Neural Fuzzy Inference System (ANFIS) controller based multiloop controller. An algorithm was proposed and applied to disturbances which are often occurred by starting of induction motors, and also occurred by short circuit fault in three phase system. The point of common coupling (PCC) voltage will be restored by the current limitation and protects the DVR itself. In this paper, ANFIS (Adaptive Neuro Fuzzy Inference System) controller is proposed for improvement of the transient response and elimination of steady state error. ANFIS is one of the best tradeoff between neural and fuzzy systems, providing smoothness. The proposed ANFIS based DVR system is designed and implemented using MATLAB/SIMULINK.**

***Keywords:* Dynamic voltage restorer (DVR), Adaptive Nuero Fuzzy Inference System (ANFIS), voltage sag, voltage swells.**

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I. INTRODUCTION

Nowadays, modern industrial devices are mostly based on electronic devices such as electronic drives and custom power devices. The electronic devices are very sensitive to disturbances and become less tolerant to power quality problems. In distribution systems, voltage sag and swells are 80% of power quality problems [1].

The major power quality problems at the end user level are Voltage sag. According to the IEEE 1159-1995 standard, Voltage Sag (dip) can be defined as, "A decrease to between 0.1 and 0.9 pu in rms voltage at the power frequency for durations of 0.5 cycles to 1 minute."[2].Different methods have been used to compensate the voltage sags by considering the sensitive devices usage in modern devices. One of these methods is by using DVR.DVR counteract voltage sag [3] to improve power quality. Different methods have been found to control the DVR in different aspects.

A control approach to limit the fault current by using DVR is provided in [4].Drawback in this method is due to real power absorption, the dc link voltage of DVR increases. Minimum Energy Injection method for DVR is given in [5], energy

required for voltage restoration can be reduced by injecting voltage with a phase advance with respect to the source voltage. The controlling methods of DVR have both open loop and closed loop load voltage control [6]. Dynamic voltage restoration for high voltage purposes has been made by using the control algorithm which includes P+resonant and Posicast compensators [7] with open loop control scheme was used**.** The load voltage at steady-state will not be compensated to the desired value by using open-loop control scheme.

The multiloop control strategy of DVR was provided in [8] to overcome the above mentioned openloop control scheme problem. Due to the presence of the switching harmonics, open-loop control strategy produce poorly damped response.

To limit Downstream Fault Currents, A Dual-Functional Medium Voltage Level DVR proposed in [9]. A feedback algorithm using flux-charge-model is implemented so that it minimizes the stress in the dc link. In this, the author has not discussed about the development of transient response of the system.DVR using static compensator [13], fault ride during symmetrical and unsymmetrical faults [14], control using feed forward and state feedback schemes [15] have been given as controlling methods for DVR. In this paper, multiloop control system using ANFIS and Posicast controller is proposed for the controlling of DVR. The fault is assumed to be on the feeder parallel to the feeder where the DVR is connected [16].The Posicast controller is used to improve the transient response and ANFIS controller is used to eliminate the steady state error. The flux control algorithm is proposed to limit the fault current.

II.DVR DESIGN AND CONTROL

The basic diagram of DVR connected to distribution system is shown in Fig. 1.Generally the DVR consists of a storage unit, dc-link capacitors, a PWM inverter, a filter circuit, and injection transformer.

The output of the inverter has to be filtered before injecting it in to the system. So that the harmonics occurred due to switching are eliminated [17]. The injection transformer

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injects voltage in to the distribution system to compensate the load voltage during fault conditions [22].

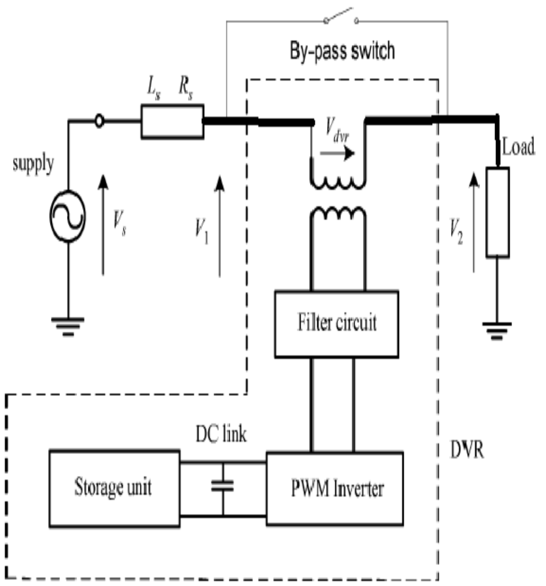


Fig. 1: DVR connected distribution system.

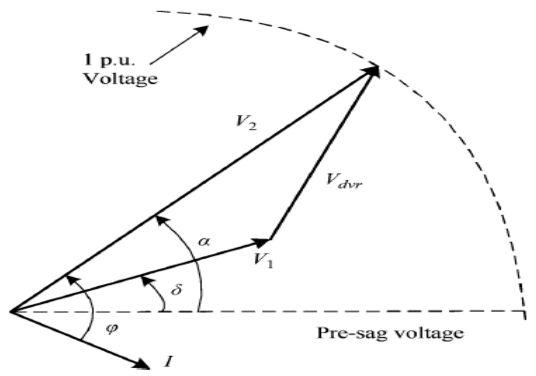


Fig. 2: phasor diagram.

The phasor diagram during voltage sag is shown in Fig. 2, $V_1$is the source voltage, V_2 is the load voltage and V_{dvr} is the voltage injected by DVR. For simplicity the voltages of only one phase are shown. The voltage required to compensate the sag is injected by DVR thereby protecting the equipment at load end. The V_1 is considered as voltage at point of common coupling V_{PCC} and V_2 is considered as voltage at load $V_{L.}$

The injection voltage V^*_{inj} can be achieved by comparing the load voltage and point of common coupling voltage.

$$V^*_L - V^*_{PCC} = V^*_{inj}$$

The position where the DVR has to be equipped in an medium voltage level distribution system is shown in Fig. 3.

Before giving the signal to the PWM inverter in the DVR, the injection voltage has to be given to Posicast controller in order to recover the transient response.

The transfer function of Posicast controller is given by

$$1 + G(s) = 1 + \frac{\delta}{1+\delta}(e^{-s^{T_d/2}} - 1$$

Where δ is the step response and T_d is the damped response signals time period. The Posicast controller responses for lightly damped transients are shown in Fig. 4.

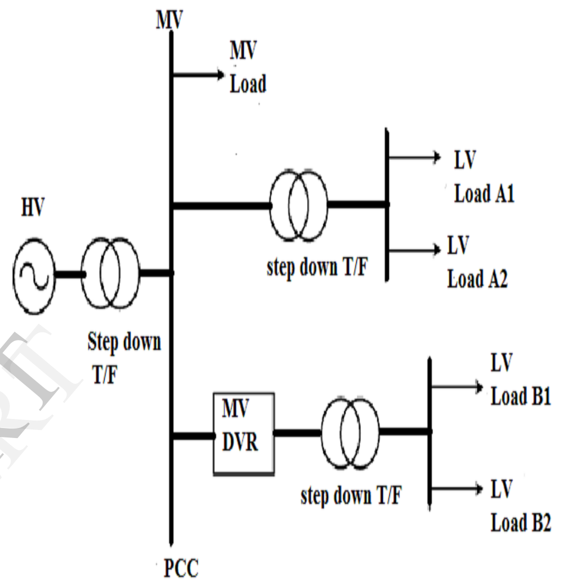
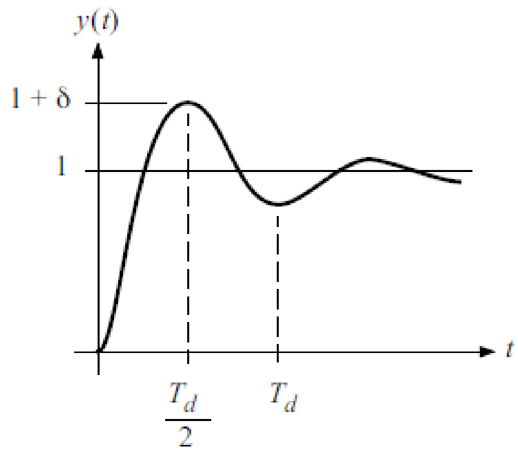


Fig. 3: Medium voltage level DVR connection.



(a)Transient response which is lightly damped

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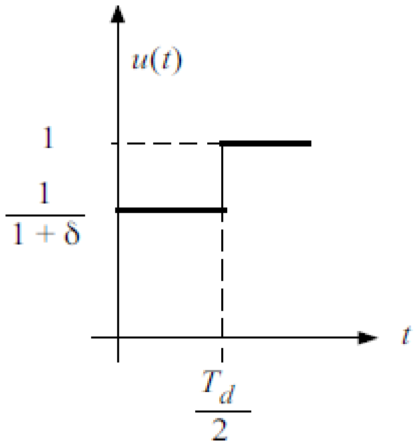
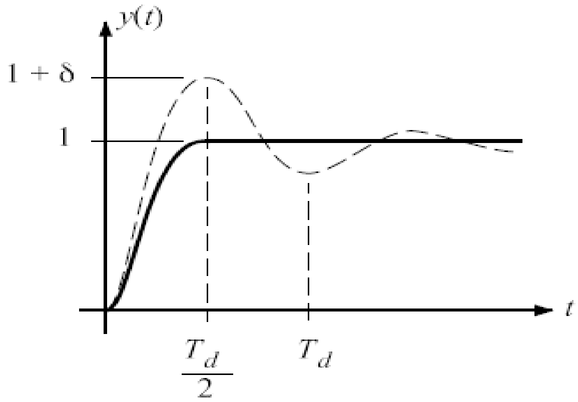


(b)Posicastcommand



(c) output response of Posicast

Fig. 4: Posicast controller response

III. Adaptive Neural Fuzzy Inference System designing for DVR

The ANFIS is a FIS implemented in the framework of an adaptive fuzzy neural network [18].ANFIS uses both the neural network and fuzzy logic approaches.

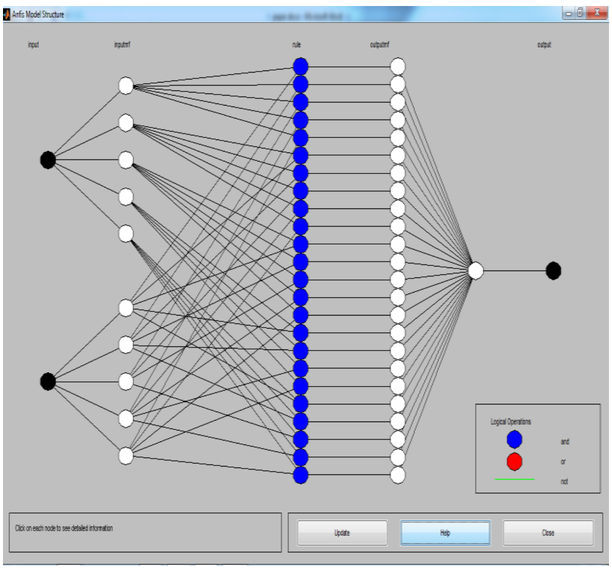


Fig. 5: Structure of ANFIS designed in MATLAB/anfisedito r.

ANFIS is generated from the initial data using MATLAB/anfis editor and the structure of ANFIS is shown in Fig. 5. The fuzzy inference system used here is Takagi – Sugeno type [19]. The generated FIS has been trained using ANFIS [20]. The error function (ξ= V^*_L – V^*_{PCC}) is derived from the difference between the point of common coupling voltage and the voltage at the load end.

The derived error function is given to the ANFIS controller and the same error is used to tune the parameters. The Architecture of Adaptive Neuro Fuzzy Inference System is shown in Fig. 6.where (*x*1 and *x*2 are two inputs, *A*1 and *A*2 are fuzzy rules for input *x*1, and *B*1 and *B*2 fuzzy rules for input x2. w1 and w2 are firing strengths or weights.

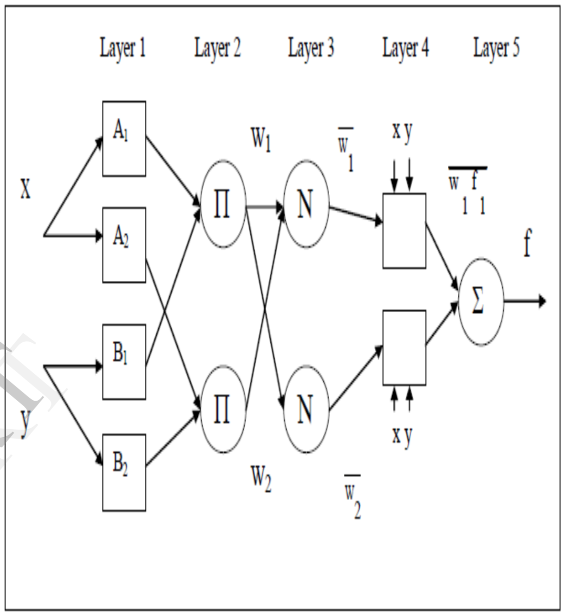


Fig. 6: Architecture of Adaptive Neuro Fuzzy Inference System.

The Architecture of ANFIS has five layers. The function of each layer is described as follows:

Layer1: Every node *i* in this layer is a square node with a node function.

$$O_i^1 = \mu_{A_i}(x)$$

Where x is the input to node i, μ is the membership function of Ai. This layer is also known as fuzzification layer.

Layer 2**:** Every node in this layer is circle node represented as II, which multiplies the incoming signals and sends the product out to the next layer. The output of each node represents the firing strength (or weight) of a rule.

$$o_i^2 = w_i = \mu_{A_i}(x)\mu_{B_i}(y)$$

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Where μ_{A_i} is the membership function of x is in Ai fuzzy set and μ_{B_i} is the membership function of y in fuzzy set of Bi.

Layer 3**:** Every node in this layer is a circle node labeled N. These layer nodes calculate rules relative weights. Where w_i^n is the normalized firing strength of i_{th} rule.

$$o_i^3 = w_i^n = \frac{w_i}{w_1 + w_2}$$

Layer 4: This layer is named rules layer which is obtained from multiplication of normalized firing strength (has been resulted in the previous layer) by first order of Sugeno fuzzy rule.

$$o_i^4 = \overline{w_i}(p_i x + q_i y + r_i)$$

Where W_i is normalized firing strength from layer 3 and {pi, qi, ri} is the parameter set of this node. These are referred to as consequent parameters.

Layer 5**:** This layer is the last layer of the network and is composed of one node and adds up all inputs of the node.

$$0_i^5 = \sum_i \overline{w}_i f_i = \frac{\sum_i w_i f_i}{\sum_i w_i}$$

Finally the output of this layer is multiplied by normalized factor and is given to the DVR through the PWM inverter.

IV. SIMULATION RESULTS

The proposed ANFIS based DVR is used to control the voltage sag during emergency condition. The disturbances which are occurred by starting of induction motors and by short circuit fault in three phase system are considered for simulation. The test system used is a 13 bus test system according to the IEEE standard whose line diagram is shown in Fig. 7.

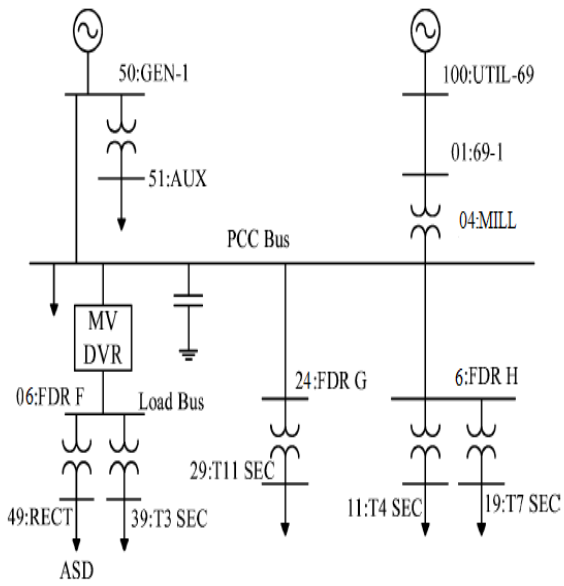

Fig. 7: 13-bus system

The entire test system is designed in MATLAB/SIMULINK software. To control the DVR, the methods discussed in section II and III were applied. For controlling each phase separately, inverter with 12-pulse was used.

The DVR component specifications are given in appendix in detail. The utility supply to the plant is taken at 69kv and distribution systems local plant which is represented by thevenin equivalent circuit that operates at 13.8kv. The equivalent impedance is 0.036+j ∠ 1.3651 Ω .The rating of p.f correction capacitors is 6000kvar.In this paper, the series resistance and leakage resistance are neglected. The DVR is placed between 04: MILL bus and 06: FDR.

A.SHORT CIRCUIT IN THREE PHASE

The fault due to three phase short circuit was applied at 24:FDR bus. The performance of DVR on the voltage of 06: FDR was studied. the specifications of control system and parameters of DVR are given in appendices I and II.

The fault is applied at t=205millisec, the circuit breaker starts working and the line between 04: MILL bus 24:FDR bus will be separated at t=285millisec.he fault is recovered and breaker rejoins the separated line to the system at t=295millisec. The results of simulation are shown in Fig. 8.During the fault, the V_{rms} of PCC drops to a value about 0.3p.u as shown in enlarged Fig. With the use of DVR, the voltage is restored to normal value in less than half a cycle.

B. Induction Motor Starting

An induction motor is connected 04: MILL. The specification of motor is given in appendix III. The starting current of induction motor cause drop in point of common coupling voltage as shown in Fig. 9
At t=400millisec, the induction motor is started. As shown in figure, at the time of induction motor starting, the rms value of PCC voltage drops to 0.82p.u.the speed of motor

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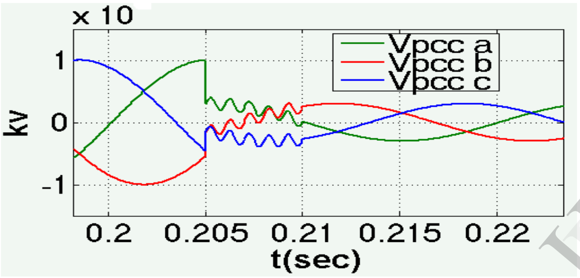
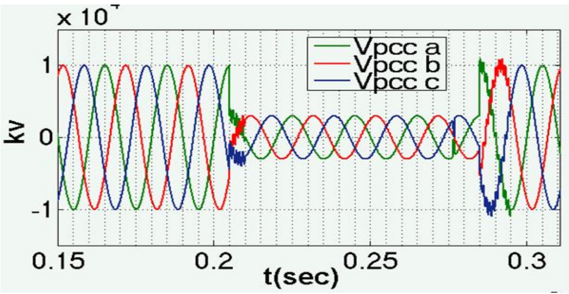
reaches to nominal value in 1sec.From time t=1.45sec, the voltage reaches to the normal value as the speed reaches to the nominal value. During these conditions, the DVR keeps the voltage of the load bus to normal value. The DVR is succeeded in restoring the voltage of load within half a cycle from the time of motor starting.

C. Limiting Of Fault Current

The final simulation is run for downstream symmetrical fault and the DVR capacity to restore the voltage of PCC and to reduce the fault current will be tested. The three phase short circuit fault is applied on 06: FDR bus. The fault current without DVR compensation is shown in Fig. 10.

The fault is applied at t=205millisec and removed at t=305millisec.During fault condition, the rms voltage of load bus decreases to zero and the DVR succeeded in restoring the voltage of point of common coupling to normal value in half a cycle which is shown in Fig. enlarged. The DVR operation is shown in Fig. 11 with the DVR compensation, the fault current is reduced from 40kA to 4kA.





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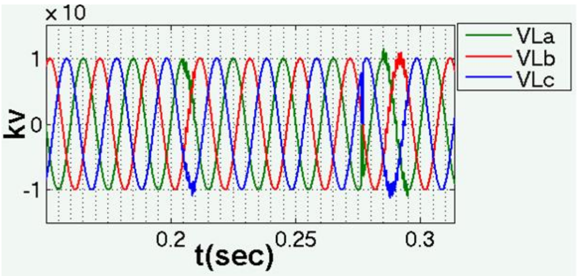

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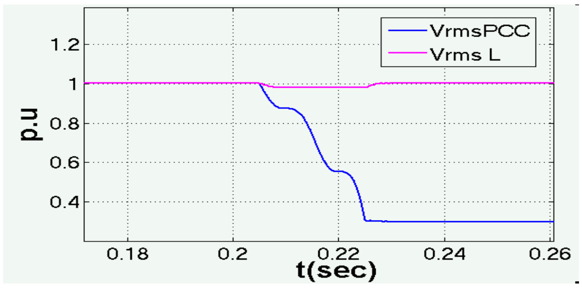

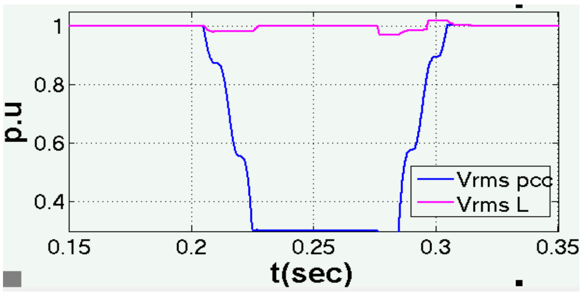

(c)

Fig. 8: compensation of 3-ph short circuit fault by DVR. (a) Voltage at the PCC. (b) Voltage at the load. (c) Vrms of load and PCC.

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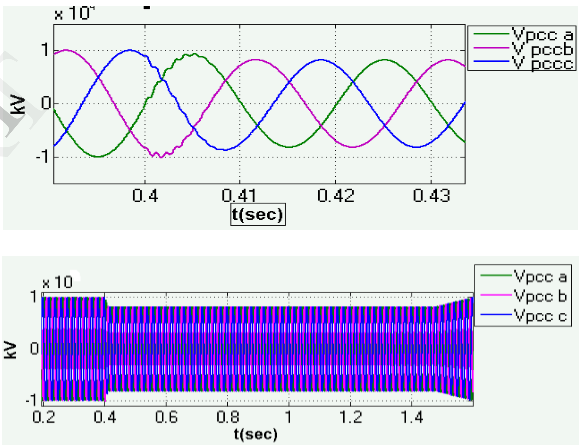

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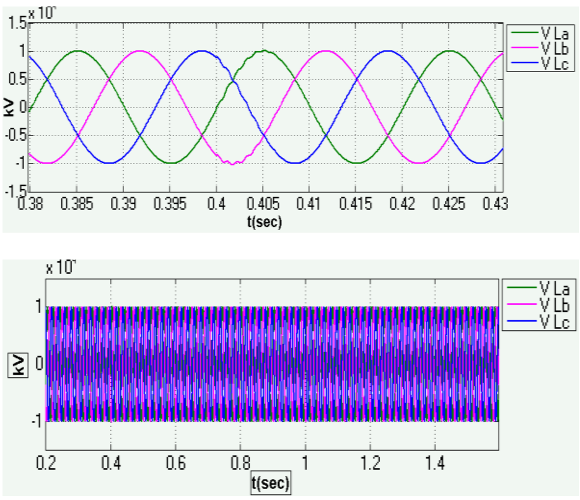

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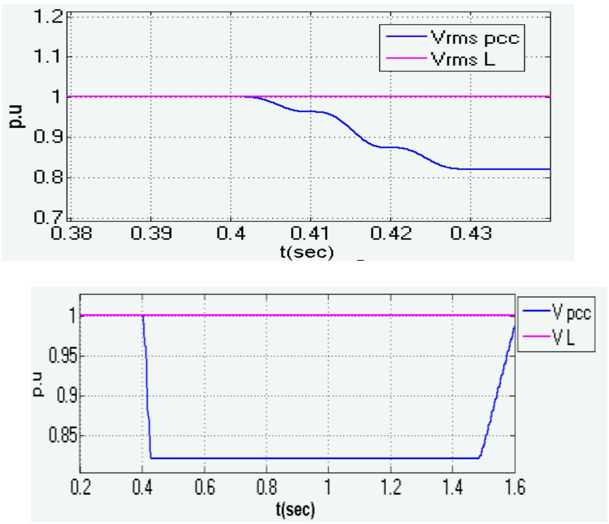


(c)

Fig. 9: DVR compensation during starting of induction motor. (a) Voltage at the PCC. (b) Voltage at the load. (c) Vrms of load and PCC.

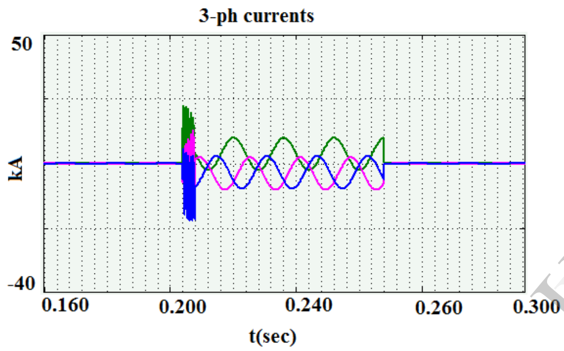
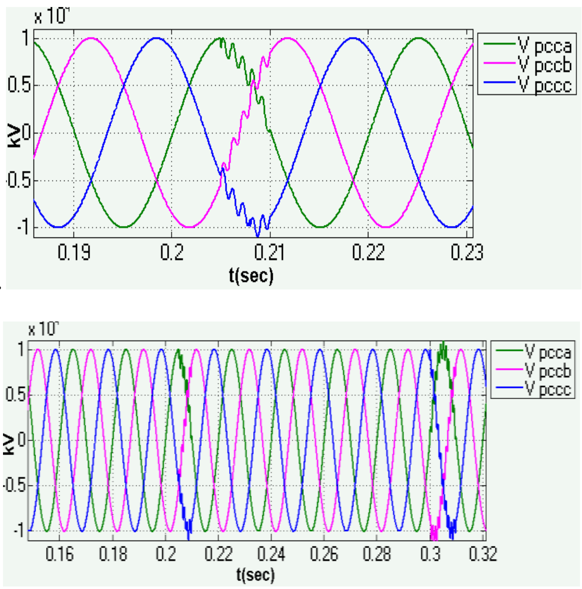
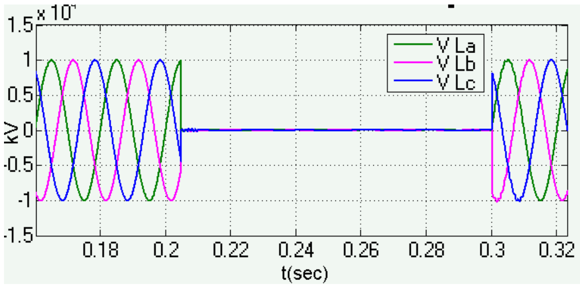


Fig. 10: 3-ph short circuit current waveforms without DVR compensation.



(a)



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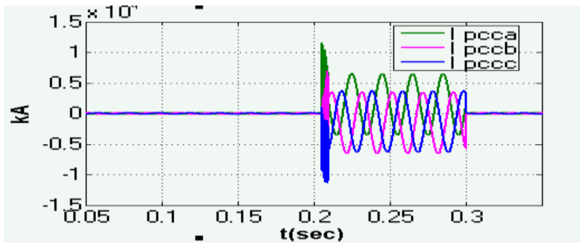

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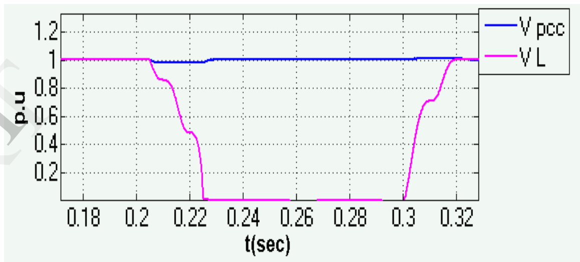

(d)

Fig. 11: Limiting of Fault current by DVR. (a) Voltage at the PCC. (b) Voltage at the load. (c) 3-ph currents. (d) Vrms of load and PCC.

V. CONCLUSION

In this paper, ANFIS based DVR is proposed to improve damping in the repose. By using ANFIS and Posicast controllers the steady state errors are eliminated and the transient response is improved. The DVR is controlled such that the downstream fault currents are limited and protects voltage of PCC during fault conditions by entering the impedance. The battery is connected in series and the impedance is entered in parallel at the starting time of fault. The proposed DVR capability and effectiveness in voltage sag compensation during short circuits, starting of induction motor and fault current limiting and protecting the voltage of PCC are verified by simulation results.

APPENDIX

I. Parameters of DVR:

Inductance of Filter (L_f) = 1.5mH
Capacitance of Filter (C_f) =1000μF
Modulation ratio of Inverter = 15 mF
Kind of DVR inverter: 12 Pulse
Capacitance of DC-link: 100mF

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Resistance entered to limit the current: 2 ohms
Inductance entered to limit the current: 3 ohms
Supply battery: 0.98*12 kV

II. Parameters of Control Systems:

δ = 1
T_d = 41.56 μs

III. Parameters of Induction Motor:

Rated power: 3 MVA
Rated voltage: 11kV
Moment of inertia: 3.7267 sec
Number of rotor squirrel cages: 1
Base Frequency: 50 Hz
Resistance of Stator: 0.004 p.u.
Resistance of Rotor: 0.3 p.u.
Inductance of Stator: 0.01023 p.u.
Inductance of Rotor: 0.05 p.u.
Magnetizing inductance: 0.9 p.u.

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