M.Manohara, M.I.S.T.E, K.Vinod Kumar and Dr.T.Devaraju / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 3, Issue 4, Jul-Aug 2013, pp.123-128

Implementation of Dynamic Voltage Restorer for Mitigation of Voltage Sag

K.Vinod Kumar PG Scholar,M.ManoharaM.Tech., M.I.S.T.E and Dr.T.Devaraju Ph.D.

Abstract

Power quality is one of major concerns in the present. It has become important, especially with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply. The dynamic voltage restorer (DVR) is one of the modern devices used in distribution systems to improve the power quality. In this paper, emergency control in distribution systems is discussed by using the proposed multifunctional DVR control strategy. Also, themultiloop controller using the Posicast and P+Resonant controllers is proposed in order to improve the transient response and eliminate the steady state error in DVR response,respectively.The proposed process is applied to some riots in load voltage effected by induction motors starting, and a three-phase short circuit fault. The three-phase short circuits, and the large induction motors are suddenly started then voltage sags areoccurred.The innovation here is that by using the Multifunctional Dynamic Voltage Restorer, improve the power quality in distribution side. Simulation results show the capability of the DVR to control the emergency conditions of the distribution systems by using MATLAB/Simulink software.

Index Terms—Dynamic voltage restorer (DVR), Power quality problems, posicast controller, P+resonant controller.

I. INTRODUCTION

Modern power systems are complex networks, where hundreds of generating stations and thousands of load centers are interconnected through long power transmission and distribution networks. The main concern of customer is the quality and reliability of power supply at various load centers. Even though power generation is most well developed countries is fairly reliable, the quality of supply is not. In power system especially the distribution system have numerous nonlinear loads, which are significantly affecting the quality of power supply. As a result, the purity of waveform of supply lost. This ends up producing many power quality problems [1].

Voltage sag and voltage swell are two of the most important power-quality (PQ) problems that encompass almost 80% of the distribution system PQ problems.Short circuits, starting large motors, sudden changes of load, and energizations of transformers are the main causes of voltage sags. Voltage sag is defined as a sudden reduction in supply voltage to between 90% and 10% of the nominal value, followed by a recovery after a short interval. Voltage swell is defined as sudden increases in supply between 110% and 180% of the nominal value of the duration of 10 milli seconds to 1 minute. Switching off a large inductive load or energizing a large capacitor bank is a typical system even that causes swells to compensate the sag/swell in a system; appropriate devices need to be installed at suitable location [2] [3].

In this paper, a Multifunctional Dynamic voltage Restorer protects the distribution side voltage using Posicast and P+Resonant controllers when the source of disturbance is the parallel feeders.Posicast and P+ResonantControllers can be used to improve the transient responseand eliminate the steady-state error in DVR. The Posicast controller is a kind of step function with two parts and is used to improve the damping of the transient oscillations initiated at the start instant from the voltage sag. The P+Resonant controller consists of a proportional function plus a resonant function and it eliminates the steady-state voltage tracking error [4].

The remainder of this paper is organized as follows: The basic arrangements of DVR and its equations are provided in section II. The operation of DVR using Posicast and P+Resonant controllers has been presented in section III.Finally, the simulation results are provided in section IV.

II. BASIC ARRANGEMENT AND EQUATIONS RELATED TO DVR

A. DVR Arrangement

The basic arrangement of a DVR is shown in fig.1. It is divided in to six categories: (i) *Energy Storage Unit:* It is responsible for energy storage in DC form. It is supplies the real power requirements of the system when DVR is used for compensation. (ii) *Capacitor:* DVR has a large DC capacitor to ensure stiff DC voltage input to inverter. (iii) *Inverter:* An Inverter system is used to convert dc storage into ac form.(iv)*Filter circuit:* Before injecting the inverter output to the system, it must be filtered so that harmonics due to switching function in the inverter are eliminated. (v)*Voltage injection transformers:* it is used for voltage injection purpose.**(**vi**)** *By pass switch***:** it is used to protect the inverter from high currents in the presence of faulty conditions. [5].

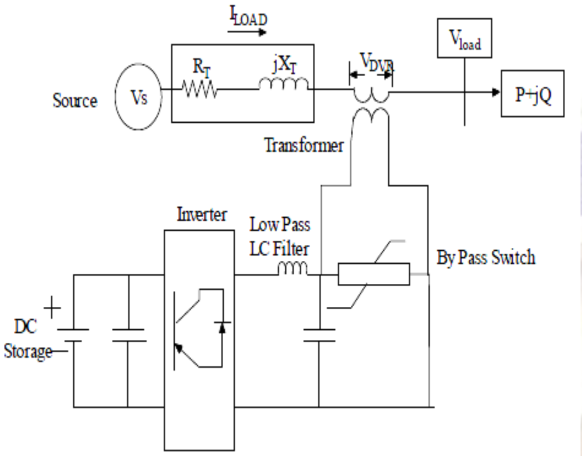


Fig.1.Basic structure of DVR

B. Equations related to DVR

Fig 2.shows the equivalent circuit diagram of DVR. The system impedance Zth depends on the fault level of the load bus .when the system voltage (Vth) drops, the DVR injects a series voltage Vdvr through the injection transformer so that the desired load voltage magnitude V_L can be maintained. The series injected voltage of the DVR can be written as

$$V_{DVR} = V_{Load} + Z_{Line} I_{Load} - V_{Source} \qquad (1)$$

Where

V_{Load} = Load side voltage
Z_{Line} = Line impedance
I_{Load} = Load current
V_{Source} = System voltage during fault condition.

The load current I_L is given by,

$$I_L = \frac{P_L + jQ_L}{V} \qquad (2)$$

When V_{Load} is considered as a reference as a equation can be rewritten as

$$V_{DVR}\,\alpha = V_{Load}\,0 + Z_{Line}\,(\beta - \theta) - V_{Source}\,\delta$$

$\alpha, \beta, \delta$are angles ofV_{DVR} ,Z_{Line} ,V_{Source} respectively and $\theta$is power angle.

$$\theta = \tan^{-1}\frac{\theta_l}{p_l} \qquad (3)$$

The complex power injection of the DVR can be written as,

$$S_{dvr} = V_{dvr} I_L \qquad (4)$$

It requires the injection of only reactive power and the DVR itself is capable of generating the reactive power [6].

III. OPERATION OF DVR USING POSICAST AND P+RESONANT CONTROLLERS

The DVR system shown in Fig. 1, controls the load voltage by injecting an appropriate voltage phasor(V_{DVR}) in series with the system using the injection series transformer. In most of the sagcompensation techniques, it is necessary that during compensation, the DVR injects some active power to the system. Therefore, the capacity of the storage unit can be a limiting factor in compensation, especially during long-term voltage sags.

The phasor diagram in Fig.3 shows the electrical conditions during voltage sag. Voltages V_1, $V_2$and V_{dvr} are the source-side voltage, the load side voltage, and the DVR injected voltage, respectively. Also, the operators I,φ, and$\delta$are the load current, the load power factor angle, the source phase voltage angle, and the voltage phase advance angle, respectively.

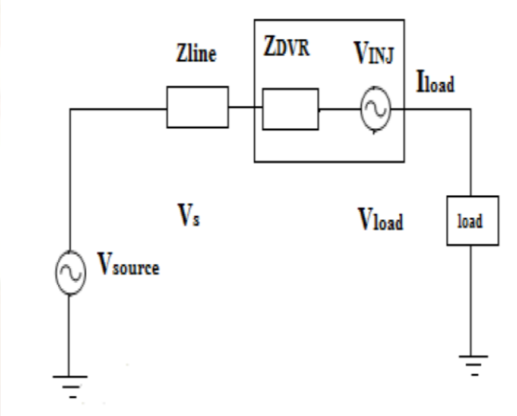


Fig 2.Equivalent circuit diagram of DVR

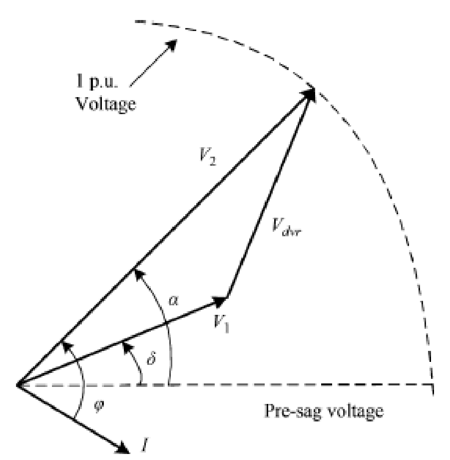
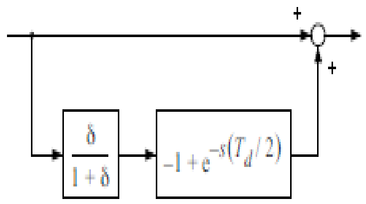


Fig. 3.Phasor diagram of the electrical conditions during a voltage sag.

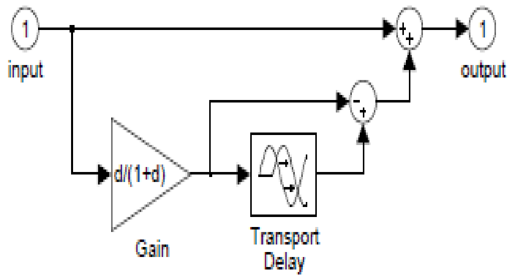
The Posicast controller is used in order to improve the transient response. Fig. 4(a) shows a typical control block diagram of the DVR. Note that because in real situations, we are dealing with multiple feeders connected to a common bus, namely “the Point of Common Coupling (PCC)”. As shown in the figure, in the open-loop control, the voltage on the source side of the DVR is compared with a load-side reference voltage so that the necessary injection voltage is derived. A simple method to continue is to feed the error signal into the PWM inverter of the DVR. But the problem with this is that the transient oscillations initiated at the start instant from the voltage sag could not be damped sufficiently. To improve the damping, as shown in Fig. 8, the Posicast controller can be used just before transferring the signal to the PWM inverter of the DVR. The transfer function of the controller can be described as follows:

$$1 + G(S) = 1 + \frac{\delta}{1+\delta}\left(e^{-S\frac{T_d}{2}} - 1\right) \qquad (5)$$

Where δ and T_d are the step response overshoot and the period of damped response signal, respectively. It should be noted that the Posicast controller has limited high-frequency gain; hence, low sensitivity to noise [4].Posicast can be easily constructed in MATLAB’s SIMULINK environment by using the transport delay block. A sample diagram is shown in Fig. 4(b) [4].



(a) Transfer function form



(b) SIMULINK diagram

Fig. 4. Block diagrams for Posicast controller.

The Posicast controller works by pole elimination and proper regulation of its parameters is necessary. For this reason, it is sensitive to inaccurate information of the system damping resonance frequency. To decrease this sensitivity, as is shown in Fig. 9, the open-loop controller can be converted to a closed loop controller by adding a multi loop feedback path parallel to the existing feed forward path. Inclusion of a feed forward and a feedback path is commonly referred to as two-degrees-of freedom (2-DOF) control in the literature. As the name implies, 2-DOF control provides a DOF for ensuring fast dynamic tracking through the feed forward path and a second degree of freedom for the independent tuning of the system disturbance compensation through the feedback path. The feedback path consists of an outer voltage loop and a fast inner current loop. To eliminate the steady-state voltage tracking error, a computationally less intensive P+Resonant compensator is added to the outer voltage loop [7]. The ideal P+Resonant compensator can be mathematically expressed as

$$G_R(S) = K_P + \frac{2K_I S\omega_{cut}}{S^2+\omega_0^2+2\omega_{cut}\, S} \qquad (6)$$

Where ω_{cut} is the compensator cutoff frequency.

Fig.5. shows the Multiloop control using the PosicastandP+Resonant controllers.

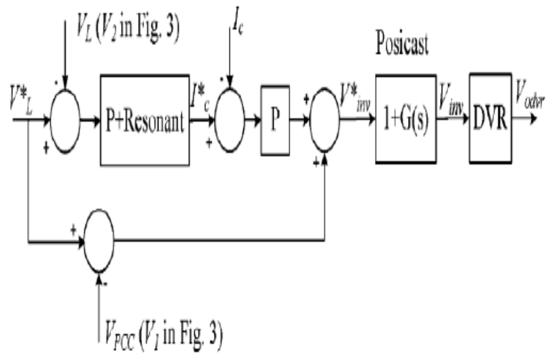


Fig.5. Multiloop control using the Posicast and P+Resonant controllers.

IV. SIMULATION RESULTS

In this part, the proposed DVR topology and control algorithm will be used for emergency control during the voltage sag. The three-phase short circuit and the start of a three-phase large induction motor will be considered as the cause of distortion in the simulations.

A. Under Study Test System

In this paper, the IEEE standard 13-bus balanced industrial system will be used as the test system. The one-line diagram of this system is shown in Fig. 6.The test system is modeled in MATLAB SIMULINK software. Control method of Fig.5 was applied to control the DVR, and the voltage, current, flux, and charge errors were included as the figures show. A 12-pulse inverter was used so that each phase could be controlled separately. Detailed specifications of the DVR components are provided in the Appendix. The plant is fed from a utility supply at 69 kV and the Local plant distribution system operates at 13.8 kV. The local (in-plant) generator is represented as a simple Thevenin equivalent. The internal voltage, determined from the converged power-flow solution, is 13.8∟-1.520 kV. The equivalent impedance is the sub transient impedance which is0.036+j∟1.3651 Ω. The plant power factor correction capacitors are rated at 6000 kvar. As is typically done, leakage and sequences resistance of the bank are neglected in this study. The detailed description of the system can be found in . In the simulations, the DVR is placed between buses "5" and "6."

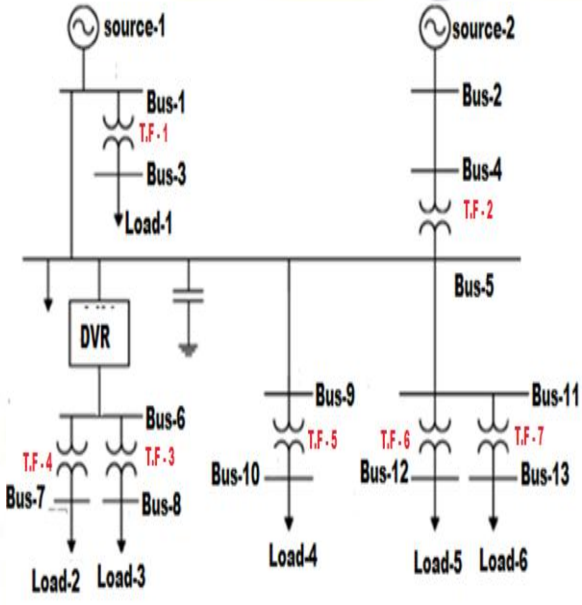


Fig. 6. Under Study test system.

B. Three-Phase Short Circuit

In this part, the three-phase short circuit is applied on"bus- 9," and the capability of the DVR in protecting the voltage on "bus- 6" will be studied.Singleline diagram is shown in fig. 7. The DVR parameters and the control system specifications are provided in Appendices A and B. At t=205 ms, the fault is applied at t= 285 ms, and the breaker works and separates the line between buses "5" and "9" from the system. At t= 305 ms, the fault will be recovered and, finally, at t=310 ms, the separated line will be rejoined to the system by the breaker. The simulation results are shown in Fig. 8. As can be seen in the figure, the rms voltage of PCC drops to about 0.25 p.u. during the fault. It is obvious that this remaining voltage is due to the impedances in the system. The DVR will start the compensation just after the detection of sag. As can be seen in the enlarged figure, the DVR has restored the voltage to normal form with attenuation of the oscillations at the start of the compensation in less than half a cycle. It is worth noting that the amount and shape of the oscillations depends also on the time of applying the fault. As can be seen in the enlarged figure, the voltage value of phase B is nearly zero; this phase has minimum oscillation when the fault starts.

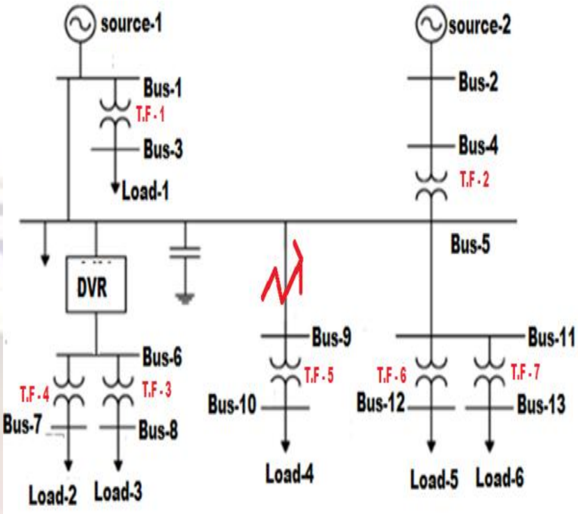
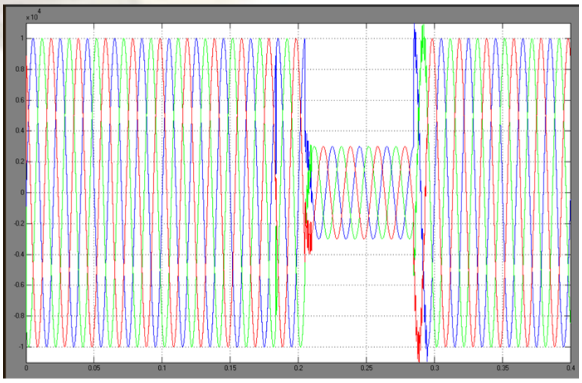


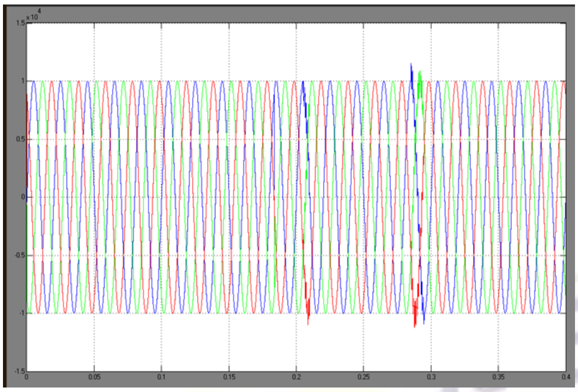
Fig.7.Single-line simulation diagram, when the 3-phase short circuit occurred in Bus-9

C. Starting the Induction Motor

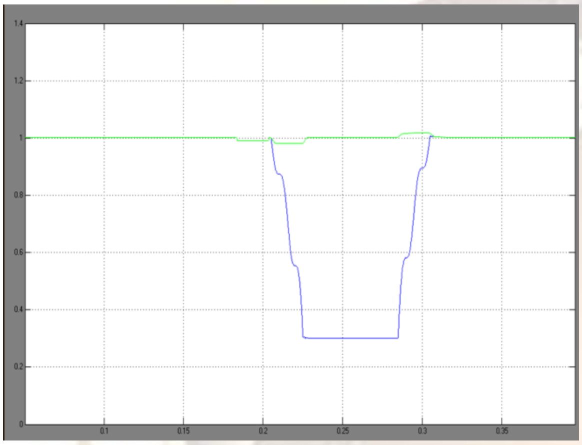
A large induction motor is started on bus "5."The motor specifications are provided in Appendix C. The large motor starting current will cause the PCC voltage (bus "5" voltage) to drop. Simulation one line diagram is shown in fig. 9. The simulation results in the case of using the DVR are shown in Fig. 10. In this simulation, the motor is started at t= 405 ms. As can be seen in Fig. 10, at this time, the PCC rms voltage drops to about 0.8 p.u. The motor speed reaches the nominal value in about 1 s. During this period, the PCC bus is under voltage sag. From 1.4 s, as the speed approaches nominal, the voltage also approaches the normal condition. However, during all of these events, the DVR keeps the load bus voltage (bus "6" voltage) at the normal condition. Also, as can be seen in the enlarged version of Fig. 10, the DVR has succeeded in restoring the load voltage in half a cycle from the instant of the motor starting.



(a)



. **(b)**



(c)

Fig. 8.Three-phase fault compensation by DVR. (a) Three-phase PCC voltages. (b) Three-phase load voltages. (c) RMS voltages of PCC and load.

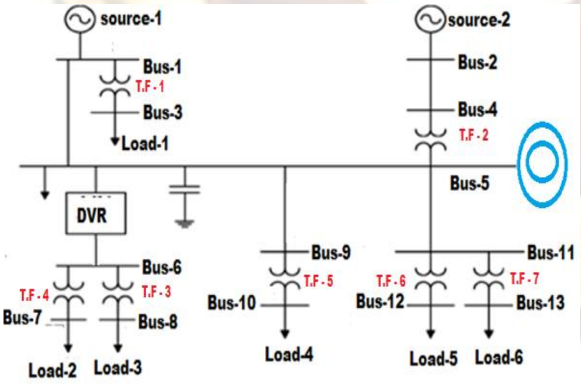
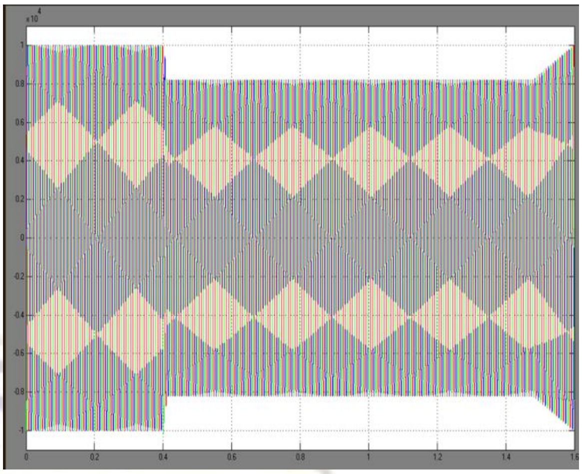
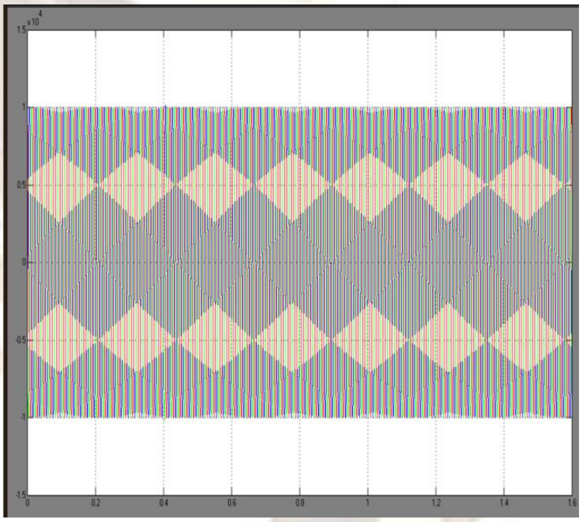


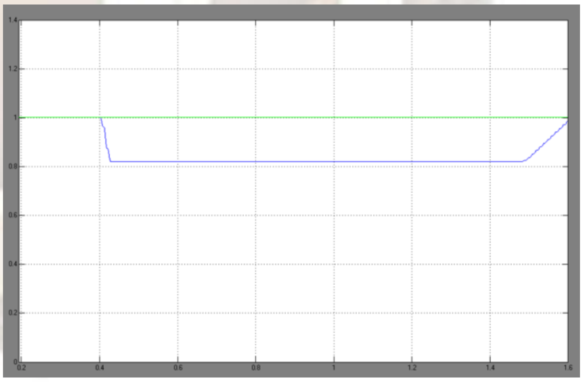
Fig.9.Single-line simulation diagram, when the induction motor is started at Bus-5.



(a)



(b)



(c)

Fig. 10.Starting of an induction motor and the DVR compensation.(a) Threephase PCC voltages. (b) Three-phase load voltages. (c) RMS voltages of PCC
and load.

V. CONCLUSION

In this paper, dynamic voltage restorer is used for protect the load side voltage against sudden changes in voltage amplitude. Also, improving the transient response of DVR responce and eliminating the steady-state error, the Posicast and P+Resonant controllers are used. The simulation results verify the effectiveness and capability of the proposed DVR in compensating for the voltage sags caused by short circuits and the large induction motor starting.

APPENDIX

DVR Parameters:

Filter inductance (Lf) =1mH
Filter capacitance (Cf) =700µF
Inverter modulation ratio=21 mF
Kind of DVR inverter: 12 Pulse
DC-link capacitance: 26 mF
Entered resistance for current limiting: 3 ohms
Entered inductance for current limiting: 2 mH
Supply battery: 12 kV.

Control System Parameters:

$\delta = 1$
Td=41.56
Kp=1
Ki=100
W0=314rad/s
Wcut=1.0 rad

Induction Motor Parameters:

Rated power: 2.4 MVA
Rated voltage: 13.8 kV
Moment of inertia: 3.7267 sec
Number of rotor squirrel cages: 1
Base frequency: 50 Hz
Stator resistance: 0.0034 p.u.
Rotor resistance: 0.298 p.u
Stator inductance: 0.0102 p.u.
Rotor inductance: 0.05 p.u
Magnetizing inductance: 0.9 p.u.

REFERENCES

[1] J. A. Martinez and J. Martin-Arnedo, "Voltage sag studies in distribution networks- part II: Voltage sag assessment," *IEEE Trans. Power Del.*, vol. 21, no. 3, pp. 1679–1688, Jul. 2006.
[2] J. A. Martinez and J. Martin-Arnedo, "Voltage sag studies in distribution networks- part I: Voltage sag assessment," *IEEE Trans. Power Del.*, vol. 21, no. 3, pp. 1679–1688, Jul. 2006.
[3] P. Hcine and M. Khronen, "Voltage sag distribution caused by power system faults," *IEEE Trans. Power Syst.*, vol. 18, no. 4, pp. 1367–1373, Nov. 2003.
[4] John Y. Hung, "Posicast Control Past and Present," IEEE MULTIDISCIPLINARY ENGINEERING EDUCATION MAGAZINE., VOL. 2, NO. 1, MARCH 2007.
[5] H.P.Tiwari, Sunil Kumar Gupta,"Dynamic Voltage Restorer Based onLoad Condition, "International Journal of Innovation,Management and Technology.,vol.1,No.1,April 2010.
[6] ShairulWizmarWahab and Alias MohdYusof, "Voltage Sag and Mitigation Using Dynamic Voltage Restorer (DVR) System,"ELECTRIKA.,vol.8,no.2,2,32-37,2006.
[7] KaithamalaiUdhayakumar, Ponnusamy Lakshmi, KandasamyBoobal," Hybrid Posicast Controller for a DC-DC Buck Converter," SERBIAN JOURNAL OF ELECTRICAL ENGINEERING.,Vol. 5, No. 1, May 2008, 121-138.
[8] [8] Y. W. Li, D. M. Vilathgamuwa, P. C. Loh, and F. Blaabjerg, "A dualfunctional medium voltage level DVR to limit downstream fault currents," *IEEE Trans. Power Electron.*, vol. 22, no. 4, pp. 1330–1340, Jul. 2007.

K.Vinod Kumar was born in Muddanur, YSR District,AP,India, on July 09, 1988. He received the B.Tech degree in EEE from JNTUA,AP,India, in 2011. He is currently pursuing the M.Tech degree in Electrical power systems, Sree Vidyanikethan Engineering College, Tirupati,AP,India.
E-mail:vinu.honny@gmail.com

M.Manohara was born in Chittoor, AP,India, on 3rd July 1977.He received the B.E degree in Electrical and Electronics Engineering from the university of Madras in 1999 and M.Tech degree in Electrical Power Systems from JNTUCE,Anantapur.
He is presently working as Associate professor in department of EEE, SreeVidyanikethan Engineering College, Tirupati. His interesting areas are Electrical Machines, Power systems, Control systems, Power quality, Non-conventional energy sources etc.
E-mail:muppirimanohar@yahoo.com

Dr.T.Devaraju is presently working as HOD and professor in the department of EEE, SreeVidyanikethan Engineering College, Tirupati.