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Simulation And Comparison Of Control Strategies Of DVR For Compensating Volatge Sags

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Abstract

Distribution system needs to be protected against voltage sags, dips & swells that adversely affect the reliability & quality of power supply at the utility end. DVR (Dynamic voltage restorer) is one possible solution to such power quality problems and acts as a protection barrier for sensitive equipments whilst restores the voltage timely. This comprehensive paper addresses the comparison of different controllers namely PI, Fuzzy & hybrid Fuzzy-PI on the basis of THD level & output waveforms. The 11kV distribution systems with linear and non-linear loads are simulated and tested using MATLAB/SIMULINK. The effectiveness of different control techniques based DVRs to analyze their feasibility and practicability during voltage sag condition have been investigated. The simulation results of the recommended system states the better reliability & compatibility of non-linear techniques with non-linear loads than the system with linear techniques with non-linear loads.

Keywords: DVR, Fuzzy logic controller, Hybrid Fuzzy-PI, PI controller, Voltage sag.

I. INTRODUCTION

The economy invested in the distribution system is large enough to take into account the concept of equipment protection against various disturbances that affects the reliability of not only the distribution system but the entire power system incorporating generation & transmission too. The wide acceptance of sophisticated electronic devices at the utility end deteriorates the quality of supply & utility is suffering from its bad effects on large scale. The various power quality problems[1] encompass the voltage sags, voltage dips & voltage swells, flickers, harmonics & transients accompanied by unbalanced power, which are results of various faults with three phase fault being the most severe among all, starting of induction motor which is most often used due to its rugged construction, switching off large loads and energizing of capacitor banks. The higher index of reliability & power quality [2] to satisfy the customer has reflected the need for the development & application of compensation systems. Compensating systems [3] also known as the custom power devices offer a handful of protection & security to the system under observation. They tend to absorb the various disturbances by injecting appropriate voltage, current or both into the system; thereby relieving the main source from meeting the reactive power demand of the load. This paper attempts to demystify the various control strategies providing a reliable solution to the faulted system with the help of DVR (Dynamic voltage restorer).This series conditioner device is capable of generating or absorbing real and reactive power with the help of its essential components, namely power circuit & control circuit. Various control techniques are available to obtain a controlled output voltage, to be injected into the system. They are known as Linear & Non-linear techniques. A PI controller with a linear structure offers satisfactory performance over a wide range of operation [4] . The problem encountered by the controller is the setting of PI parameters i.e. the gains (K_p, K_i). In the influence of varying parameters and operating conditions, the fixed gains of linear controller don't adapt accordingly to give good dynamic response. To overcome the problems faced by a linear technique, non-linear technique is an effective solution [5]. The recommended system uses the PI, Fuzzy [6][7][8] and Hybrid Fuzzy-PI

[9] logic controllers to investigate the performance level of various controllers in a regard to increase the capability of the existing system by creating immunity from disturbances. Simulation results of voltage sag condition for a linear & non-linear load are presented.

II. CONFIGURATION OF DVR

The DVR consists of the following main components whose description is given below:

A. Voltage Source Inverter:

It forms the building block of compensating device. It performs the power conversion process from DC to AC. VSI consists of fully controlled semiconductor power switches to form a single phase or three phase topologies. For medium power inverters, IGBT's are used and GTO's or IGCT's due to compact size & fast response for high power inverters are employed. The single phase VSI topology encompasses a low-range power applications and medium to high power applications are covered by the three phase topology [10].

B. Series Injection Transformer:

It provides electrical isolation & voltage boost to the system. In a 3-phase system, either 3 single phase units of isolating transformer or 3-phase isolating transformer can be employed for the purpose of voltage injection. Proposed system uses 3 single phase units of isolating transformer with unity turns ratio.

C. Filters:

These are electronic circuits comprising of combination of passive elements; resistors, inductors & capacitor.LC type of filters corrects the harmonic output from VSI to provide compensation in the required phase of the 3 phase system boosted by DVR.

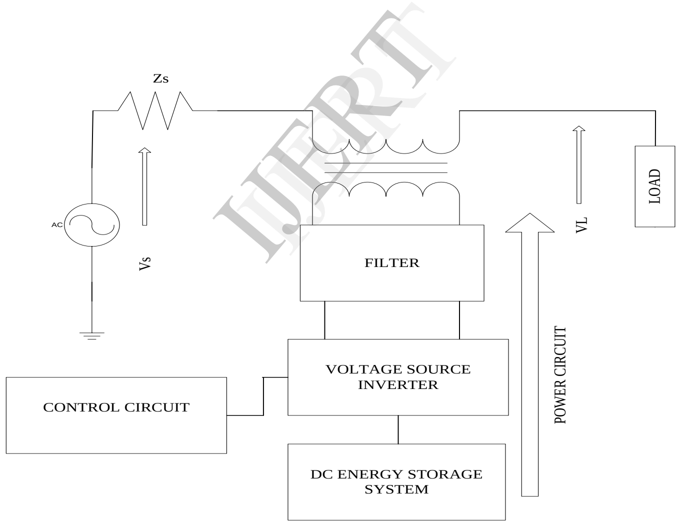

Fig.1: Block diagram of DVR using PI controller

III. CONTROL PHILOSOPHIES

It controls the system output by generating an appropriate control signal prior to the unbalanced condition prevailing in the system. It generates the signals to enable the VSI (voltage source inverter) by providing proper firing sequence to the circuit. Three control philosophies have been used namely, PI, Fuzzy & Fuzzy-PI.These are discussed as below:

A. PI CONTROLLER BASED DVR

The linear PI adjusts its proportional & integral gains K_p & K_i in order to reduce the steady state error to zero for a step input as shown in fig.2. It is widely used due to simple control structure but suffers a disadvantage of fixed gains i.e. it cannot adapt itself to the varying parameters & conditions of the system.

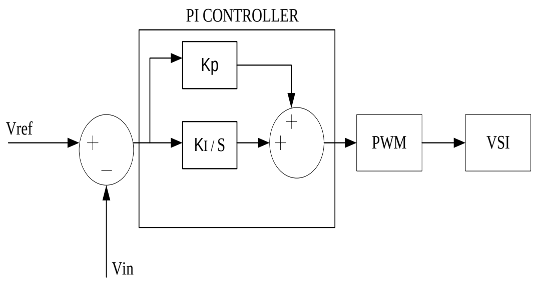

Fig.2: Control strategy of PI Controller

Table I: System Parameters

Sr.No	System Quantities	Standards
1.	Source	3-Phase,13kV,50Hz
2.	Inverter Parameters	IGBT based,3arms,6 Pulse, Carrier frequency-1080Hz Sample time=50µsec
3.	PI Controller	Kp=0.5,Ki=50,sample time=50µsec
4.	RL Load	Active power=1KW,Reactive power=400VAR
5.	Three Winding Transformer	Y/Δ/Δ 13/115/115kV
6.	Two Winding Transformer	Δ/Y 115/11 kV

B. FUZZY CONTROLLER BASED DVR

The drawback suffered by PI controller is overcome by Fuzzy. In comparison to the linear PI controller, this is a non-linear controller that can provide satisfactory performance under the influence of changing system parameters & operating conditions [11][12]. The function fuzzy controller is very useful as relieves the system from exact & cumbersome mathematical modeling & calculations. The performance of fuzzy controller is well established for improvements in both transient & steady state [8]. The fuzzy controller comprises of four main functional modules namely; Knowledge base, Fuzzification, Inference mechanism & Defuzzification. The FLC controller of the tested system exploits the Mamdani type of inference method. It defuzzifies the crisp input-output variables into fuzzy trapezoidal membership function and reverse process of Defuzzification is based upon the Centroid method as given in tableIII. The controller core is the fuzzy control rules as shown in table I. which are mainly obtained from intuitive feeling and experience [14].

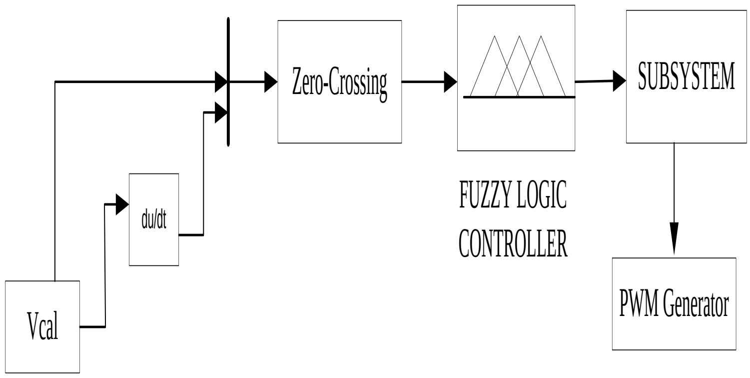

Fig.3: Control Strategy of Fuzzy Controller

Table II: Fuzzy Rule Based System

“e” “ce”	NL	NM	NS	Z	PS	PM	PL
NL	L	L	L	M	Z	S	Z
NM	L	L	M	Z	Z	Z	S
NS	L	M	S	Z	Z	S	S
Z	M	S	S	Z	S	S	M
PS	S	S	Z	Z	S	M	L
PM	S	Z	Z	Z	M	L	L
PL	Z	S	Z	M	L	L	L

Table III: FIS Details

FIS Variables	Input-2 ,Output-1
FIS Name	DVR Fuzzy
FIS Type	Mamdani
Membership Function	Trapezoidal
And Method	Min
OR Method	Max
Implication	Min
Aggregation	Max
Defuzzification	Centroid

C. HYBRID FUZZY-PI CONTROLLER BASED DVR

The hybrid Fuzzy-PI control scheme uses fuzzy as adjustor to adjust the parameters of proportional gain Kp and integral gain Ki based on the error e and the change of error Δe [14]. Fuzzy-PI based Controller has been designed by taking inputs as error which is difference between measured voltage and reference voltage of DVR for voltage regulator and its derivative while ΔKp and ΔKi as output for voltage regulator where Kp and Ki are proportional gain and integral gain respectively [15] as shown in fig.3.

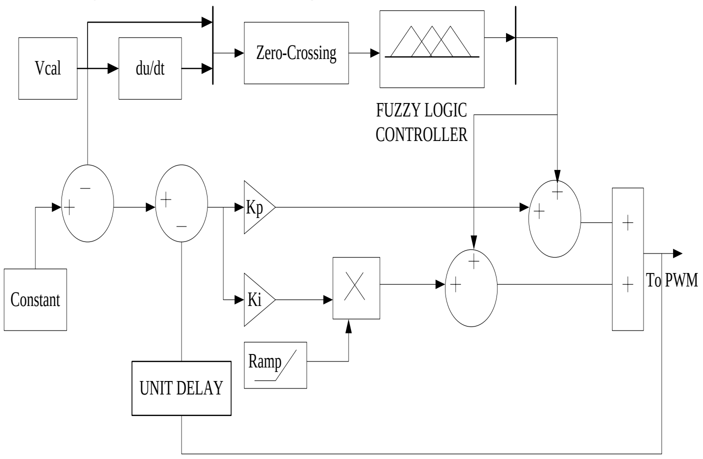

Fig.4: Control Strategy of Fuzzy-PI Controller

IV. SIMULATION RESULTS

In the SIMULINK model, two feeders are drawn from the same supply using 3-winding transformer. One of the feeders is compensated using DVR while the other uncompensated. These are further connected to identical loads so that their performances are fairly compared. The PI controller based DVR, fuzzy controller based DVR and PI-fuzzy controller based DVRs are connected one by one in the compensated feeder to compare their performances. The loads investigated in this work are static linear and static non-linear loads. The uncompensated load voltage waveform along with its frequency spectrum is depicted in fig.5.

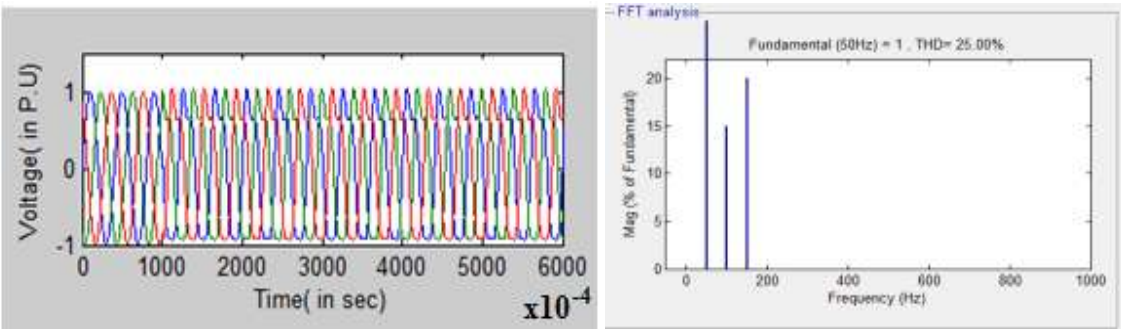

Fig.5: Voltage waveform & FFT analysis of uncompensated system

A. *CASE 1*

In the SIMULINK model, two feeders are drawn from the same supply using 3-winding transformer. One of the feeders is compensated using DVR while the other uncompensated. The PI controller based DVR is investigated for static linear and static non-linear loads. From the simulation results, it is seen that that the PI controller based DVR reduces the THD level of uncompensated system from 25% as in fig 5 to 15% in fig 6 for static linear load and for static non-linear load, it is reduced from 25% to 23.70% as in fig 7.

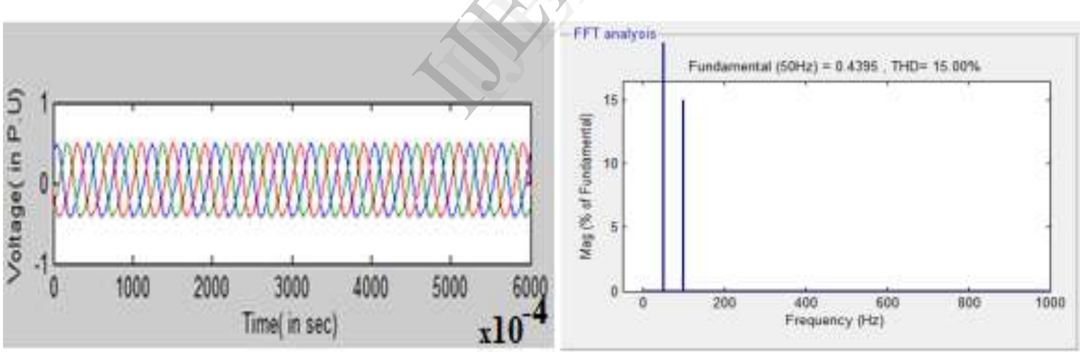

Fig.6: Load Voltage waveform and its frequency spectrum when compensated using PI Controller based DVR

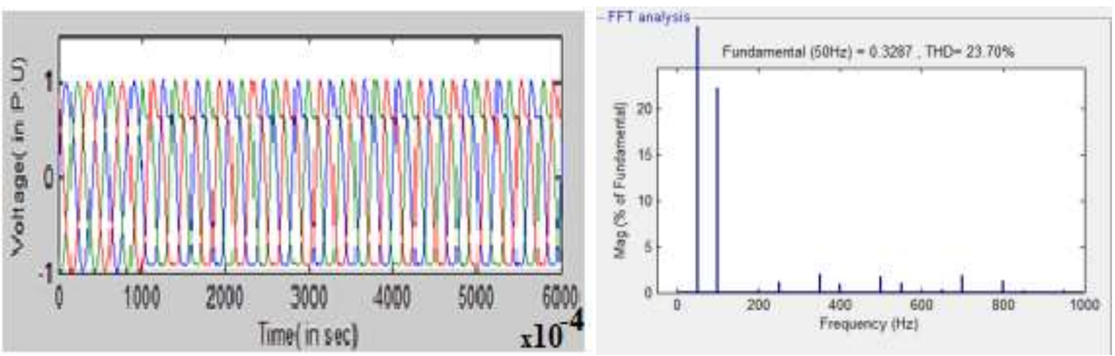

Fig.7: Load Voltage waveform and its frequency spectrum when compensated using PI Controller based DVR

B. CASE 2

In this case, fuzzy logic controller is employed to compensate the uncompensated system shown in fig.4. Unlike, linear PI control scheme as discussed in case (A), it is a non-linear technique that uses trapezoidal membership function & rule base system as given in table II to adjust accordingly to the varying system parameters & conditions. It overcomes the disadvantage suffered with linear PI controller by providing better compensation & reducing the THD level of uncompensated system from 25% as in fig.4 to 17.49% of compensated system as in fig.9 for static non-linear load. The voltage waveform & its frequency spectrum depict the effectiveness of fuzzy in reducing harmonics as compared to PI for static non-linear load.

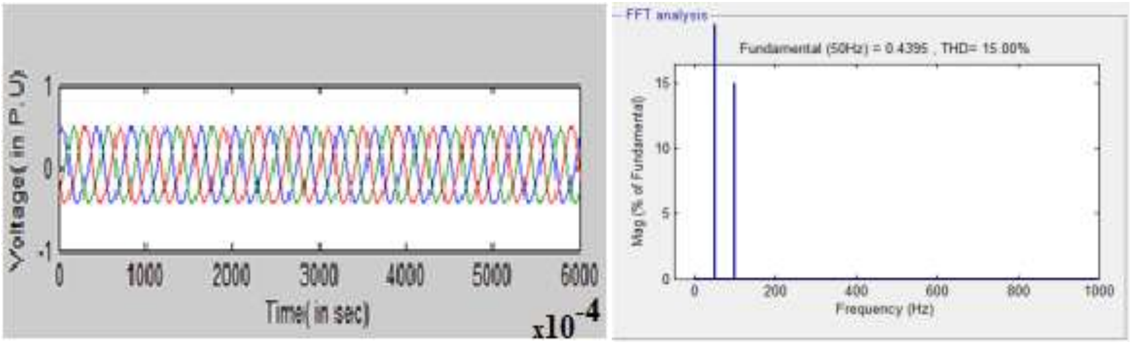

Fig.8 Load Voltage waveform and its frequency spectrum when compensated using Fuzzy Controller based DVR

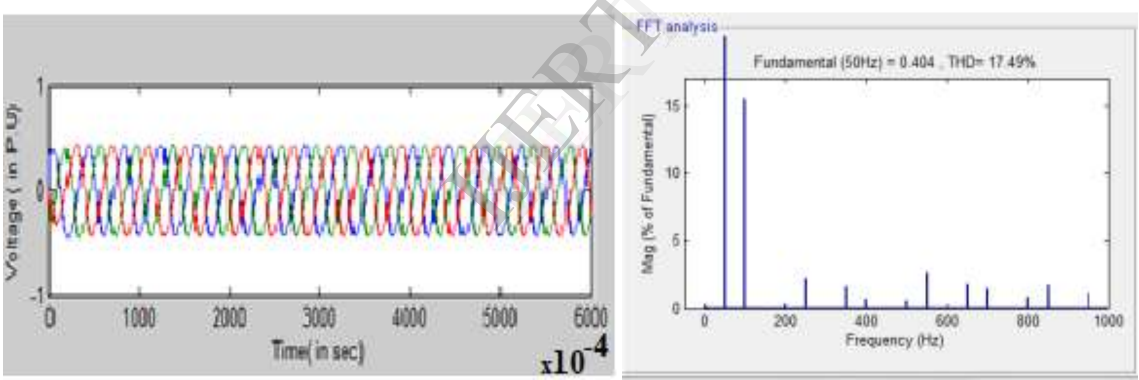

Fig.9 Load Voltage waveform and its frequency spectrum when compensated using Fuzzy Controller based DVR

C. CASE 3

In this case, hybrid Fuzzy-PI control scheme is employed & tested for static linear & non-linear loads. This hybrid controller adjusts the proportional & integral gains Kp & Ki of PI using the trapezoidal membership function & the rule base system for regulating the voltage of the system. As seen from the load voltage waveform & frequency spectrum of uncompensated system in fig 4, the THD level is reduced effectively from 25% to a much less value of 16.68% as in fig 11. Load voltage waveforms & frequency spectrum of hybrid control scheme for static non-linear load in fig 11depicts that the harmonics are effectively reduced to a less value as compared to 23.70% with PI controller in fig 7 & 17.49% with Fuzzy controller in fig 9.

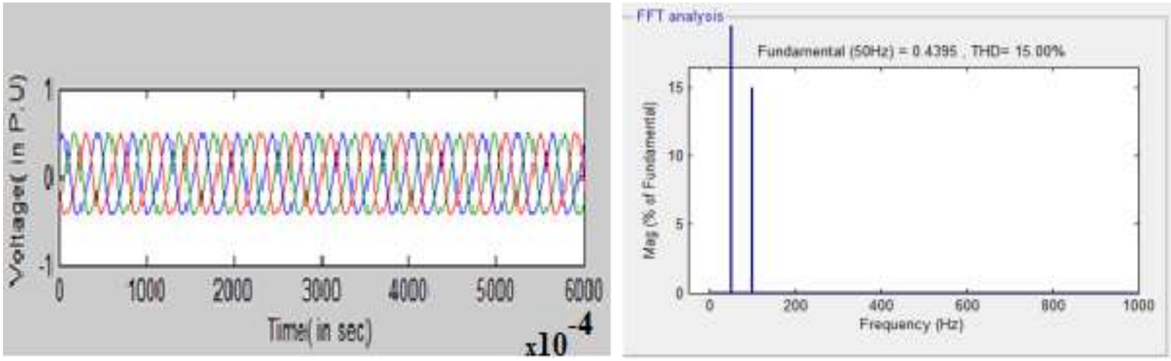

Fig.10 Load Voltage waveform and its frequency spectrum when compensated using Fuzzy-PI Controller based DVR

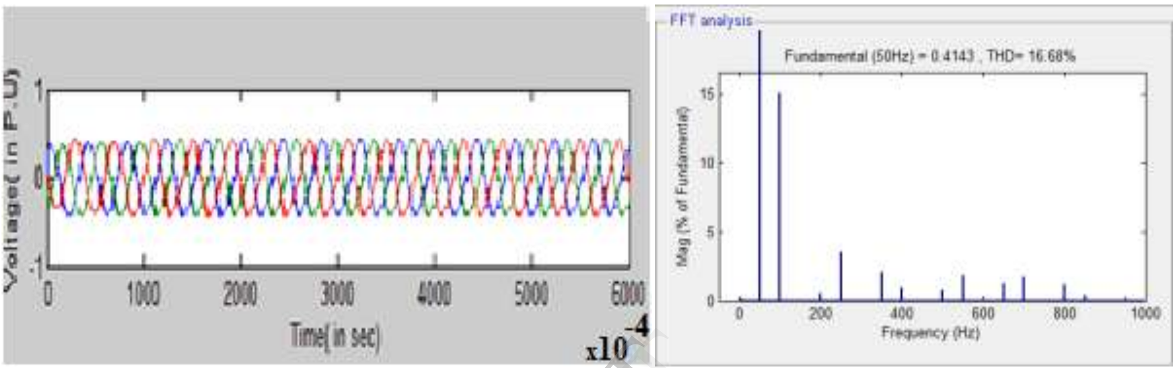

Fig.11 Load Voltage waveform and its frequency spectrum when compensated using Fuzzy-PI Controller based DVR

V. CONCLUSIONS

The effectiveness of different control techniques based DVRs for static linear & static non-linear loads have been investigated. Simulation results indicate that the non-linear control techniques provide better compensation to the system as compared to the linear PI technique based DVR connected to the feeder during static non-linear loads.

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