International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 3 Issue 7, July-2014, pp: (41-48), Impact Factor: 1.252, Available online at: www.erpublications.com

# THD Reduction in DVR by Firefly-Fuzzy Logic

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**Abstract: This paper describes the minimisation of total harmonic distortions in a transmission line. DVR is used for this purpose. But the controlling of DVR voltage injection is done by three different controllers: PI, Fuzzy Logic and Firefly-Fuzzy Logic. A comparison is shown amongst these three techniques. Every technique is checked for voltage sag and swell.**

## I. INTRODUCTION

Power quality is an important issue for electricity consumers at all levels of usage, particularly industries and the services sector. We extensively use sensitive power electronic equipment and non-linear loads these days in industry, commercial and domestic applications. In such an environment, problems like voltage sag, swell, transients, harmonics distortion ,voltage imbalance ,noise, are encountered .To solve these problems various custom power devices are used.DVR is one of most effective and custom power device that is used for compensation of voltage sag and voltage swell[3,4 ]. A voltage sag is defined as the sudden reduction of the supply voltage by 90% to 10% of the nominal, followed by a recovery after a short period of time. The typical duration of a sag is 10ms to 1 minute. The main causes of voltage sag are Faults on the transmission or distribution network, Faults in consumer's installation, Connection of heavy loads and start-up of large motors. voltage swell is not as much common as voltage sag. A voltage swell is defined as the increase in r.m.s voltage between 1.1-1.8 p.u. at power frequency for duration of 0.5 cycle to 1 min. switching off a large load or energizing a large capacitor bank are main causes of voltage swell.[1,3,4 ]

DVR is normally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC)..It is based on pulse width modulated Voltage source inverter ,which is capable of generating or absorbing real or reactive power independently[3,4 ]. Compensation of voltage occurs in both direction ,increase the voltage in case of sag and reduce the Voltage in case of swell. The DVR consists of .an Injection / Booster transformer , Harmonic filter, Storage Devices, Voltage Source Converter (VSC), DC charging circuit ,Control and Protection system. The DVR operates in two, the standby mode and the boost mode. In the standby mode (VDVR=0), No switching of semiconductors takes place in this mode of operation, as the individual converter legs are triggered so as to establish a short-circuit path for the transformer connection. Therefore, only the comparatively low conduction losses of the semi-conductors in this current loop contribute to the losses. The DVR will be in this mode most of the time. In the boost mode (VDVR>0), the DVR injects a compensation voltage through the booster transformer due to detection of a supply voltage disturbance.

Power quality by using DVR, if controlled intelligently, can be improved to a great extent. Various methods have been adopted recently by researchers. Instead of PI controlled DVR, fuzzy logic controlled DVR is used previously or in combination with bio optimised techniques as in fuzzy logic membership function is fixed and depends upon rule structure predetermined by the user's interpretation of the characteristics of the variables in the model. Considering these points, during our work following objectives will be fulfilled

- Development of DVR with a proposed hybrid control technique named Firefly-Fuzzy
- Comparison of proposed work with PI controlled DVR in terms of voltage sag and swell mitigation efficiency, disturbance removal efficiency and three phase to ground error removal.

## II. PROPOSED ALGORITHM

DVR is used to control injected voltage into transmission line to compensate faults whether sag or swell. For this purpose IGBT controlled by pulse width modulator is used. The pulse width of PWM can be controlled and for this purpose some controllers like PI, fuzzy logic and firefly optimised fuzzy logic, are used here. Fuzzy logic algorithm's performance depends upon its membership functions and rule sets. When rules and membership functions are designed for a specific task then these are considered to be fixed. But due to change in system conditions steady state error changes. So to minimise steady state errors, membership function should be continuously changing with initial condition change. So position of membership functions is optimised. In our work this is done by firefly optimisation. Firefly is discussed later in this paper. Time consumed in iterations to minimise the steady state error can be set by iteration number and number of bacteria's considered. Total number of positions in membership functions, decides searching space dimensions. In this work as shown in figure 2.1, 7 membership functions for each input and output are used. Positions of these are fixed initially. Two types of membership functions are used: trapezoidal and triangular. In error input, either one or two position vector of function coincides, this reduces the dimension of searching space to a great extent. Triangular function has three positions [x1, x2, x3], satisfying condition x1<x2<x3. As is seen in figure 1, the middle position of NM coincides with starting position of NS and similar other membership functions also have some common positions, reducing total of 4 positions to be optimised to minimise the steady state error for single input.

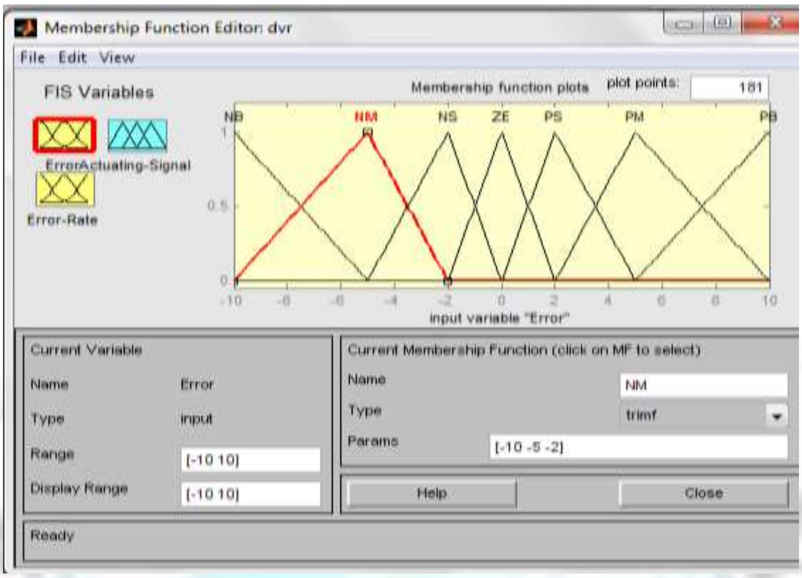



**Figure 1: Membership function of input 'error'**

Since there are two inputs and one output, so total of 12 positions of membership functions are to be tuned by firefly algorithm. It means in firefly optimisation every single firefly will search in twelve searching spaces for nutrition. During optimisation an objective function is decided which minimise the steady state error. For every firefly twelve positions of membership functions are changed and new fuzzy logic is evaluated for given error. Here in this work integral square error (ISE) is taken to objective function and used as input for evaluation of fuzzy logic. After all complete iterations error is minimised and that instantaneous positions of membership functions are used as new positions in fuzzy logic.

## III. FIREFLY OPTIMISATION

Firefly Algorithm (FA) was first developed by Xin-She Yang in late 2007 and 2008 at Cambridge University, which was based on the flashing patterns and behavior of fireflies. In essence, FA uses the following three idealized rules:

- Fireflies are unisex so that one firefly will be attracted to other fireflies regardless of their sex.
- The attractiveness is proportional to the brightness, and they both decrease as their distance increases. Thus for any two flashing fireflies, the less brighter one will move towards the brighter one. If there is no brighter one than a particular firefly, it will move randomly.
- The brightness of a firefly is determined by the landscape of the objective function.

As a firefly's attractiveness is proportional to the light intensity seen by adjacent fireflies, we can now define the variation of attractiveness $\beta$ with the distance r by

$$\beta = \beta_o e^{-\gamma r^2}, \qquad (1)$$

where $\beta_o$ is the attractiveness at r = 0.

The movement of a firefly i is attracted to another more attractive (brighter) firefly j is determined by

$$x_i^{t+1} = x_i^t + \beta_o e^{-\gamma r_{ij}^2}\left(x_j^t - x_i^t\right) + \alpha_t \in_i^t \qquad (2)$$

where the second term is due to the attraction. The third term is randomization with $\alpha_t$ being the randomization parameter, $\in_i^t$ and is a vector of random numbers drawn from a Gaussian distribution or uniform distribution at time t.

If $\beta_o = 0$, it becomes a simple random walk. On the other hand, if $\gamma = 0$, it reduces to a variant of particle swarm optimization. Furthermore, the randomization $\in_i^t$ can easily be extended to other distributions.

### Parameter Settings

As $\alpha_t$ essentially control the randomness (or, to some extent, the diversity of solutions), we can tune this parameter during iterations so that it can vary with the iteration counter t.

So a good way to express $\alpha_t$ is to use

$$\alpha_t = \alpha_o \delta^t \quad (3)$$

where $\alpha_o$ is the initial randomness scaling factor, and $\delta$ is essentially a cooling factor. For

most applications, we can use $\delta$ = 0.95 to 0.97.

Regarding the initial $\alpha_o$, simulations show that FA will be more efficient if is associated with the scalings of design variables. Let L be the average scale of the problem of interest, we can set $\alpha_o$= 0.01L initially. The factor 0.01 comes from the fact that random walk requires a number of steps to reach the target while balancing the local exploitation without jumping too far in a few steps.

The parameter $\beta$ controls the attractiveness, and parametric studies suggest that $\beta_o = 1$ can be used for most applications. However, should be also related to the scaling L. In general, we can set $\gamma = 1/\sqrt{L}$. If the scaling variations are not significant, then we can set $\gamma = O(1)$.

For most applications, we can use the population size n = 15 to 100, though the best range is n = 25 to 40

### Algorithm Steps

**Begin**

1) Objective function: $f(\mathbf{x}), \quad \mathbf{x} = (x_1, x_2, ..., x_d)$;
2) Generate an initial population of fireflies $\mathbf{x}_i \quad (i = 1, 2, \ldots, n)$;.
3) Formulate light intensity $I$ so that it is associated with $f(\mathbf{x})$
   (for example, for maximization problems, $I \propto f(\mathbf{x})$ or simply $I = f(\mathbf{x})$;
4) Define absorption coefficient $\gamma$

**While** (t < MaxGeneration)
  **for** i = 1 : n (all n fireflies)
    **for** j = 1 : n (n fireflies)
      **if** ($I_j > I_i$),
        move firefly i towards j;
      **end if**
      Vary attractiveness with distance r via $\exp(-\gamma\, r)$;
      Evaluate new solutions and update light intensity;
    **end for** j
  **end for** i
  Rank fireflies and find the current best;
**end while**

Post-processing the results and visualization;

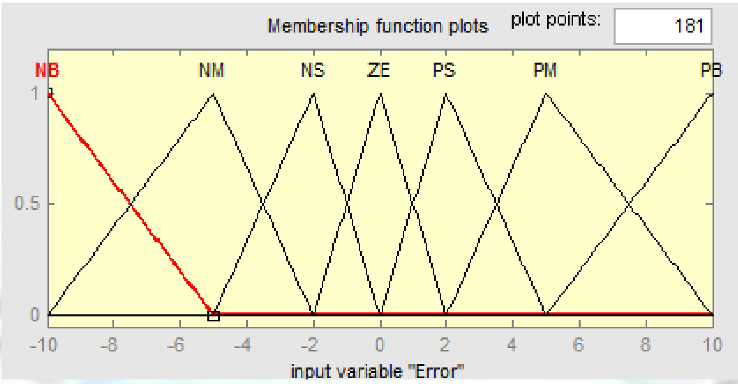
**end**

## IV. RESULTS & DISCUSSION

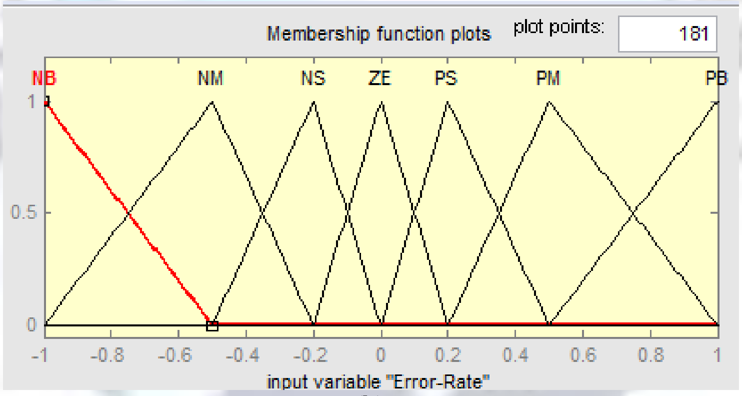
Before optimising fuzzy logic, rules and membership function have to be defined. In our case a 'dvr.fis' named fuzzy logic structure is designed in MATLAB whose decision table is shown in table1.

| Ce\e | NB | NM | NS | Z | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| NB | NB | NB | NB | NM | NM | NS | Z |
| NM | NB | NB | NM | NM | NS | Z | PS |
| NS | NB | NM | NM | NS | Z | PS | PM |
| Z | NM | NM | NS | Z | PS | PM | PM |
| PS | NM | NS | Z | PS | PM | PM | PB |
| PM | NS | Z | PS | PM | PM | PB | PB |
| PB | Z | PS | PM | PM | PB | PB | PB |

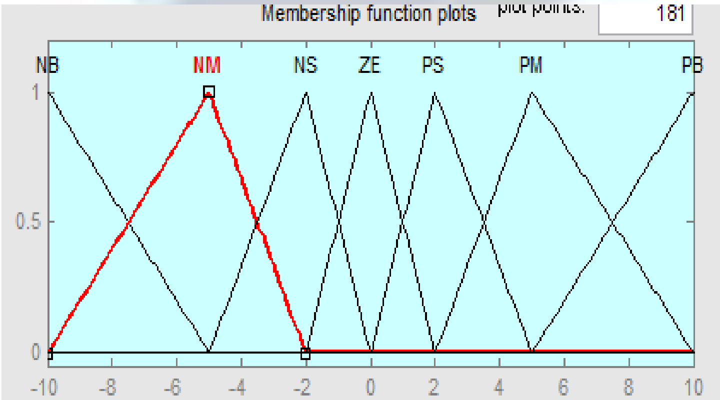
Membership function defined in 'dvr.fis' are shown in figure 4.1 below.




(a)




(b)




(c)

**Figure 2: Membership function (a) error signal (b) Error rate (c) Actuating Output Signal**

Fuzzy logic function takes two inputs: error and error rate and gives one output whose membership functions are shown in figure 2. In this paper total harmonic distortions are minimised and compared using PI, fuzzy logic and firefly trained fuzzy logic for voltage sag and swell. The proposed simulink model is shown in appendix. Fourier transform is applied on output signal to check THD (%). The output waveform and fft analysis of output in case of PI controller is selected by making constant value 3 for switch selection as shown in appendix. A voltage sag is applied by fault breaker within interval 0.1-0.3.

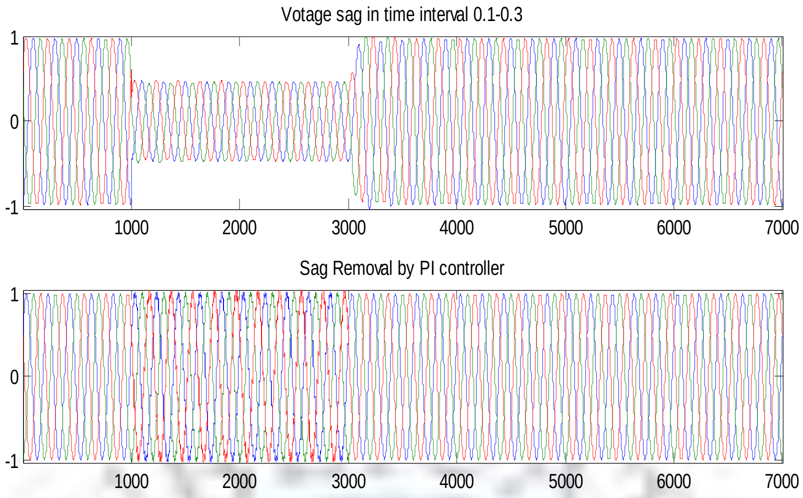



**Figure 3: Output of PI controlled sag**

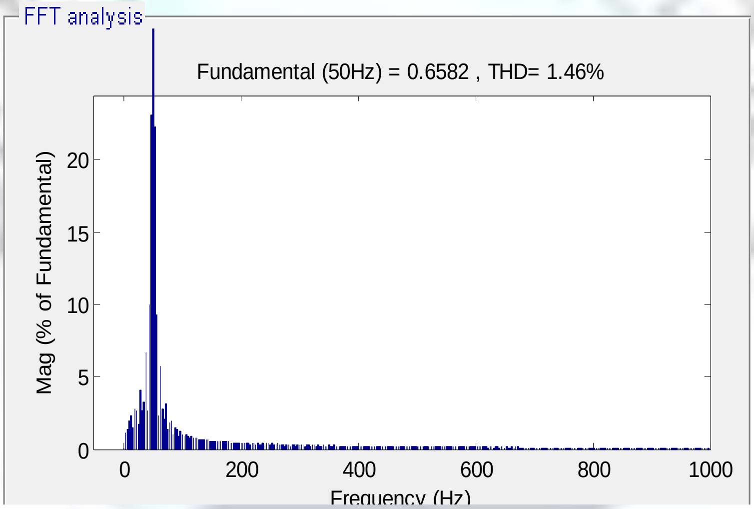



**Figure 4: THD after FFT analysis of sage introduced output**

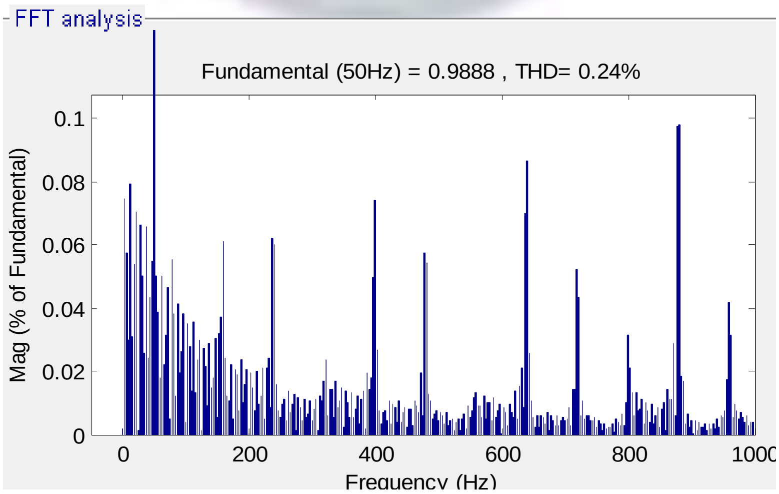
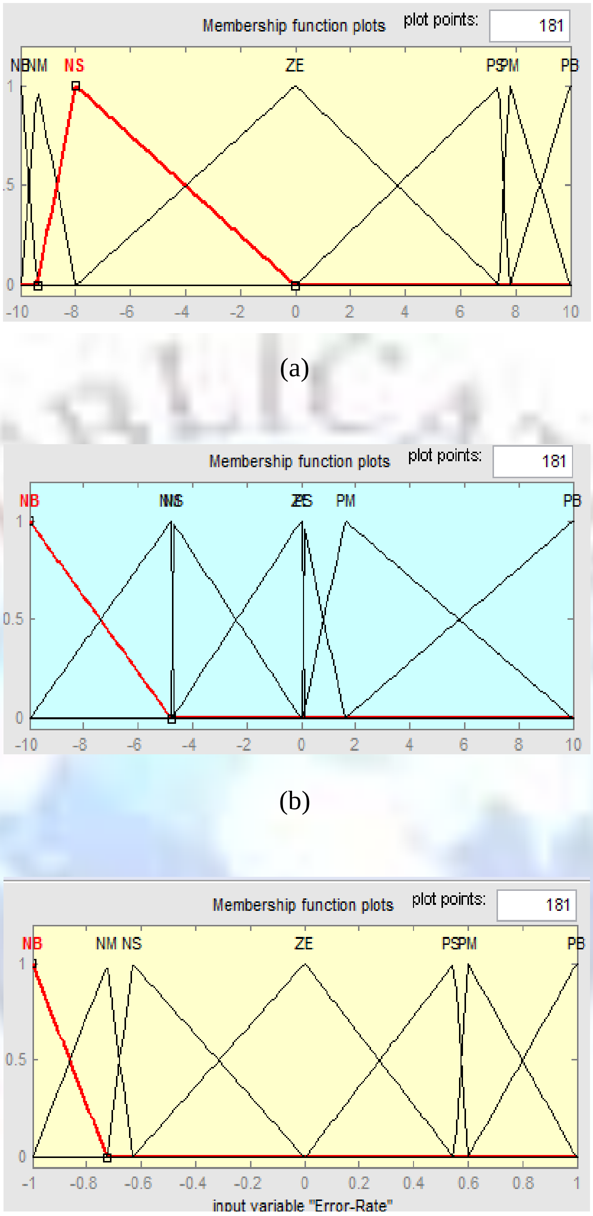



**Figure 5: THD after FFT analysis of sage compensated output**

Similarly the compensation of voltage sag is done by fuzzy logic and firefly-fuzzy logic and THD by FFT analysis is noted down. The change in membership function after firefly optimisation is shown in figure 5. New positions of each membership function is obtained after optimisation satisfying condition for a triangular membership function as discussed above. A table showing the comparison of THD(%) for every case discussed is shown in table 2.




(a) (b) ( c )

**Figure 6: Optimised Membership function (a) error signal (b) Error rate (c) Actuating Output Signal**

| | THD (%) |
|---|---|
| Without Control | 1.46 |
| PI | 0.24 |
| Fuzzy Logic | 0.20 |
| firefly- Fuzzy Logic | 0.12 |

The compensation of voltage swell by proposed algorithm is shown in figure 7 below.

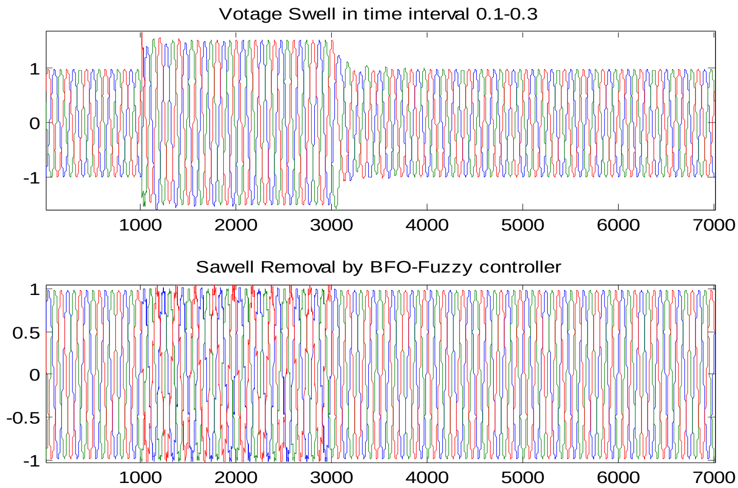



**Figure 8: Voltage Sag compensation**

## CONCLUSION

The above shown results show that fuzzy logic minimisation of THD proves better than PI controller. Performance of fuzzy system is more increased if membership functions are optimised by any optimisation algorithm. In this paper firefly foraging optimisation is used as trainer to membership functions. Table shown in results depicts clearly that after firefly optimisation THD is minimum as compared to others. Work described in this paper works well for both sag and swell compensation.

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## Appendix

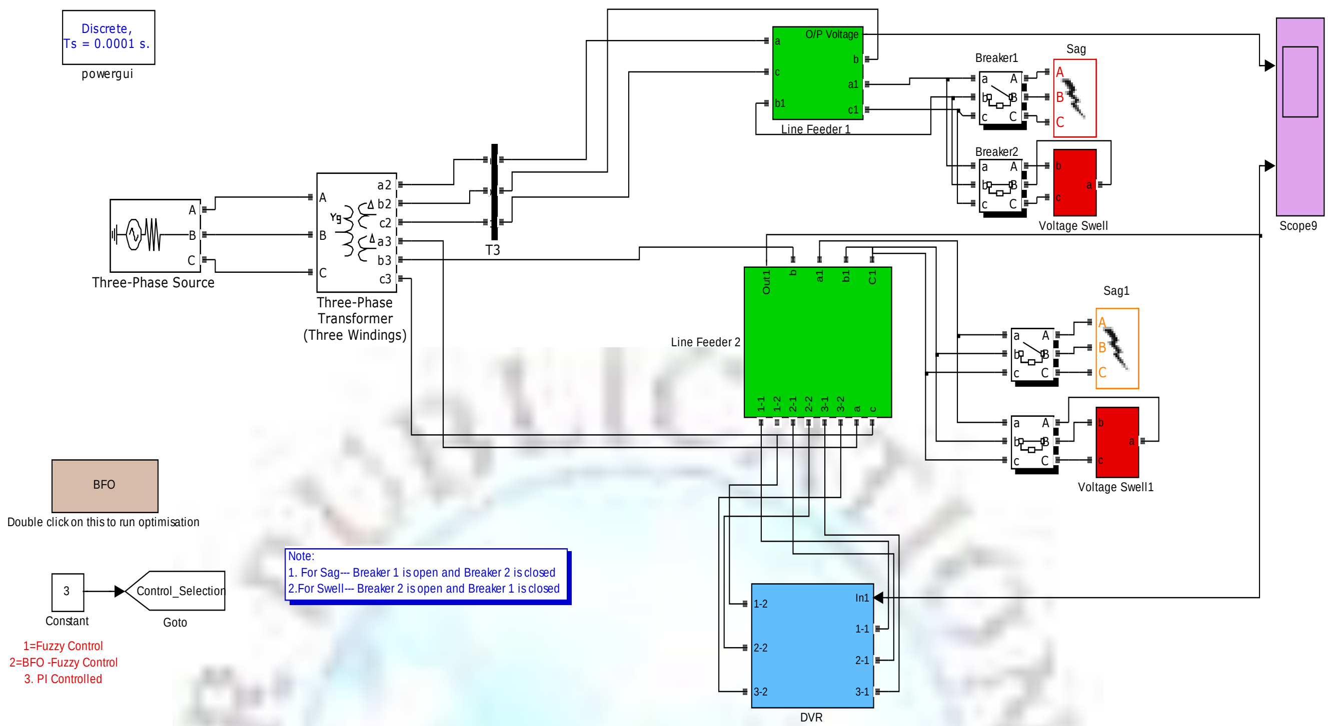


**Figure: Proposed Model for comparison of PI, Fuzzy Logic and proposed controller for THD reduction**

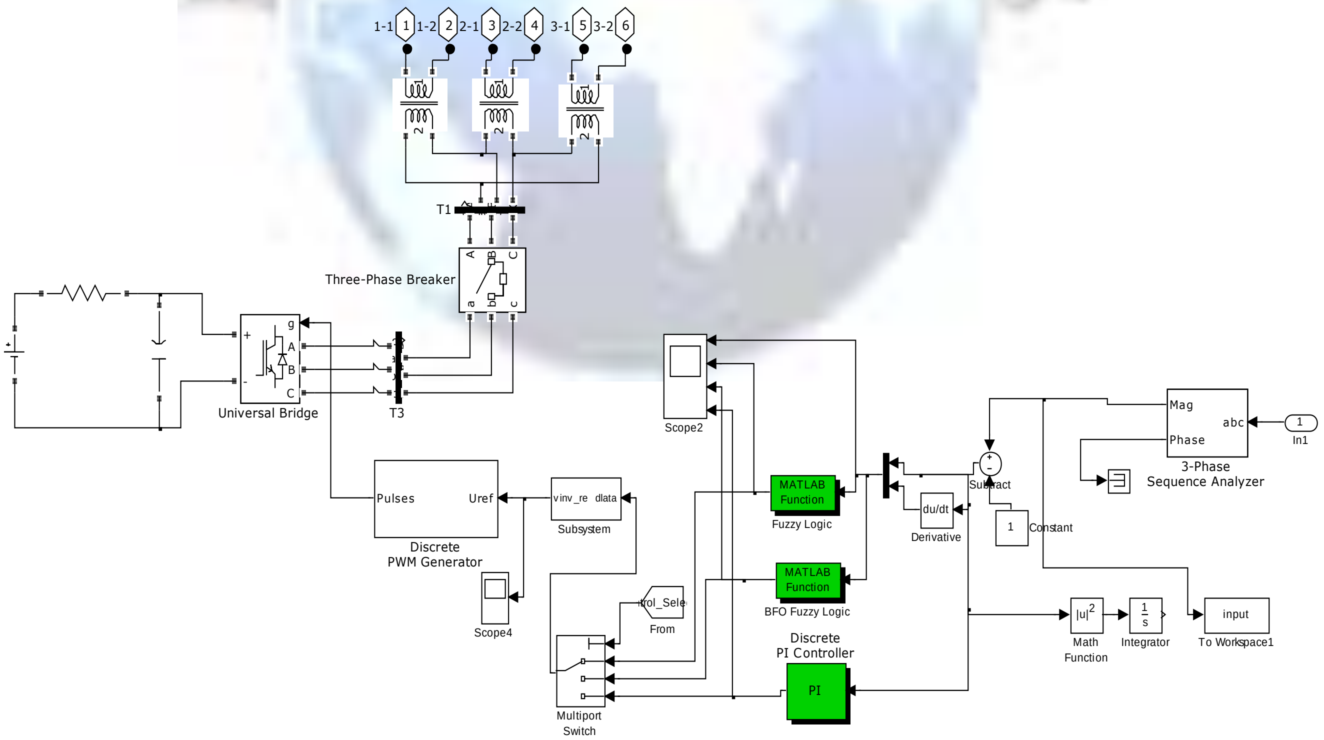


**Figure: DVR Model for proposed work having switch for PI, fuzzy Logic and BFO fuzzy logic**