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Anfis based hybrid anti islanding protection scheme for distributed generators

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Original Research

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Abstract:

In this era, distributed energy resources are sustainable solution to the energy crisis. Distributed generation generates power for local loads as well as sharing it to the main grid. The system may get islanded after the occurrence of fault. It is necessary to detect islanding earlier. It is necessary to detect islanding and provide trip signal earlier. Also, the oscillations should be damped out as early as possible to prevent instability. Harmonics are injected due to the introduction of a disturbance signal hence; total harmonic distortion should be as minimum as possible. Here adaptive network-based fuzzy inference system is used for the CEGRE LV system for the purpose of islanding detection and anti-islanding protection. An active oscillatory disturbance signal is injected in controller. Generally, proportional integral controller and fuzzy logic controller are used for anti-islanding protection. But an adaptive network-based fuzzy inference system can be used for earlier detection of islanding and also it gives better performance than a proportional-integral controller and fuzzy logic controller. System analysis is discussed by comparing Adaptive network-based fuzzy interference system performance with proportional gain controller and fuzzy logic controller by considering zero power mismatch condition. The simulation results of this proposed method is evaluated by using MATLAB Software.

Keywords: Distributed energy resources; Distributed generator; PI controller; FLC (fuzzy logic controller); ANFIS (adaptive network-based fuzzy interference system); Microgrid; Adaptive network; Zero power mismatch; Islanding; Anti-islanding; etc

1. Introduction

Nowadays, all countries are facing a problem of pollution and ozone depletion and temperature rise in the environment. The power system is becoming horizontal because large number of distributed generators are taking part in generation [1, 2]. The DGs are operating in grid connected mode or in islanded mode of operation. The DGs are also called as microsources. The capacity of these micro sources up to hundreds of megawatt [3, 4]. Small scale distributed generators are connected to distribution side and large scale distributed generations are connected to transmission system. The microsources connected to distribution system are not larger than 1 or 2 MW. These would be grid connected or standalone systems. Distributed generations are advantageous but there are some issues while operating in islanded mode of operation [5]. Islanding is nothing but isolation of part of power system and isolated system is energized by distributed generators. It is necessary to operate DGs in islanded mode to increase customer reliability [6]. Conventionally, a distribution network is passive, but these days it is no longer valid [7–9]. It is required to isolate the distributed generators from main grid earlier in case of islanding [10–12]. Islanded system have to face following issues;

1) Safety of employees working on line.
2) Violation of parameters such as voltage and frequency.
3) There may be insufficient earthing to islanded system. It can cause sudden out of phase reclosing As a result large mechanical torques and currents are created that can damage the generators or prime movers.
4) Harmonic issues may create and these issues will harm utility. Hence, it is necessary to detect islanding earlier and properly.

These days unintentional islanding is the important issue [13, 14]. Under islanding condition, the reliability of the system can be increased by continuing the part of system to be energized by connected distributed generators [15]. It is necessary to control the operation of parallel DGs while sharing the power to islanded part of the system [16]. There are three primary methods to detect the islanding are passive, active and hybrid or remote methods [17, 18]. $d-q$ reference frame is used to inject active disturbance through current controller to increase the point of common coupling voltage beyond the threshold limits to detect islanding within 2 seconds as prescribed by IEEE 1547 [19]. According to literature the hybrid anti-islanding detection techniques does not produce distortion in current waveform [20]. Virtual synchronous generator type controller is better solution for distributed generator inverters [21]. Active disturbance injection technique with AI methods can give better performance [22–24]. The parameters like voltage and frequency get disturbed hence it is necessary to detect islanding on earlier [25]. Active disturbance injection method gives small non detection zone. The d-axis voltage of distributed generators gives two different components, those are compared with defined threshold values [26–29] detect an unintentional islanding event within 90 ms.
PI controller and fuzzy logic controller are used for anti-islanding protection [30–32]. Where fuzzy logic controller gives better results than PI controller. It is expected that the system should identify the islanding and trip the DGs as early as possible to maintain stability. ANFIS can provide trip signal earlier than the PI and FLC controller. Also signal oscillations dies out earlier in case of ANFIS. The disturbance signal is injected in current controller which introduces the harmonics in system, ANFIS reduces the total THD. With overall discussion ANFIS gives better performance than PI and FLC controller. Contribution of this work is, with the implementation of ANFIS; system can give better performance than both techniques; PI controller and FLC. Zero Power Mismatch is the worst case scenario in the power system. If there is active power imbalance (mismatch) then there is frequency variations due to improper threshold and hence it is difficult to distinguish islanding condition. So this condition is considered while performing analysis of system.
This paper is organized as follows: section 1 explains about the introduction and literature review, section 2 depicts about the system configuration, and section 3 explains about the results and discussion and section 4 ends with concluding the proposed work.

2. System configuration

Our system configuration has been detailed in the following sections:

2.1 Control plan utilized for the distributed generators

A standard IEEE 1547 anti-islanding test system is used for hypothetical study to observe the consequences of active disturbance introduction through d-axis current control loop of the converter as shown in Fig. 1. The control method used for grid connected converter is represented in Fig. 2.

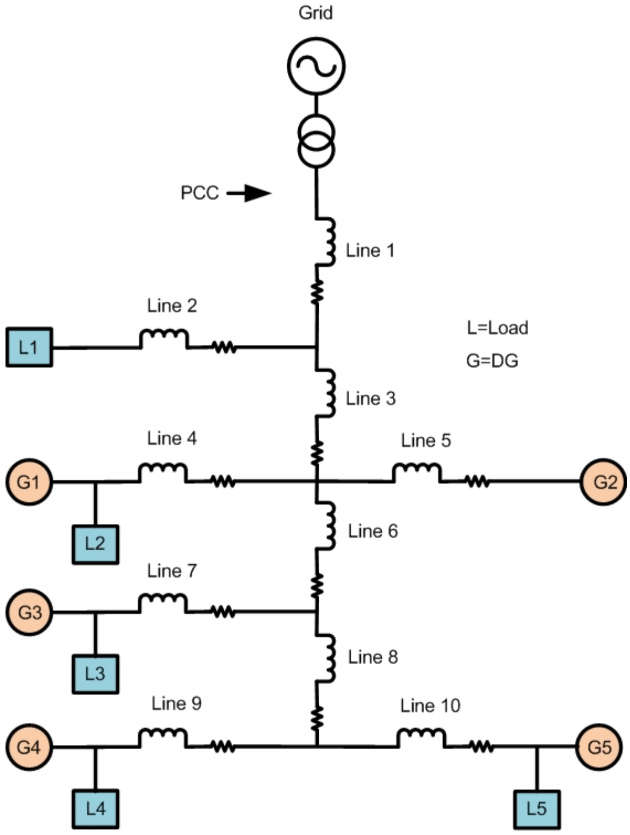

Figure 1. Block diagram of the proposed system.

The PQ control algorithm is used and it is assumed that the dc bus voltage does not change with respect to time. The mathematical representation for the real and reactive power shared by the distributed generators can be given as,

$$P = \frac{3}{2}(V_d I_d + V_q I_q) \tag{1}$$

$$Q = \frac{3}{2}(V_d I_q - V_q I_d) \tag{2}$$

where P, Q, V_d, V_q, I_d and I_q are real and reactive power shared by DGs, d and q axis voltage and current of grid respectively. The phase lock loop with synchronous reference frame will orient the grid voltage vector along the d axis. Hence q-axis voltage value will be zero. Hence, the reference current for controller loop of the converter can be given as follows:

$$I_d^* = \frac{2}{3V_d} P^* \tag{3}$$

$$I_q^* = -\frac{2}{3V_q} Q^* \tag{4}$$

where, I_{d^*}, I_{q^*} , P^*, and Q^* are the set point values of d ,q axis current, real and imaginary power of the converter, respectively. The mathematical representation for the active fluctuating disturbance signal being introduced through the d-axis current control loop of the converter as shown in Fig. 2 can be given as follows:

$$I_{ds} = K I_d^* \sin(\varpi_{ds} t) \tag{5}$$

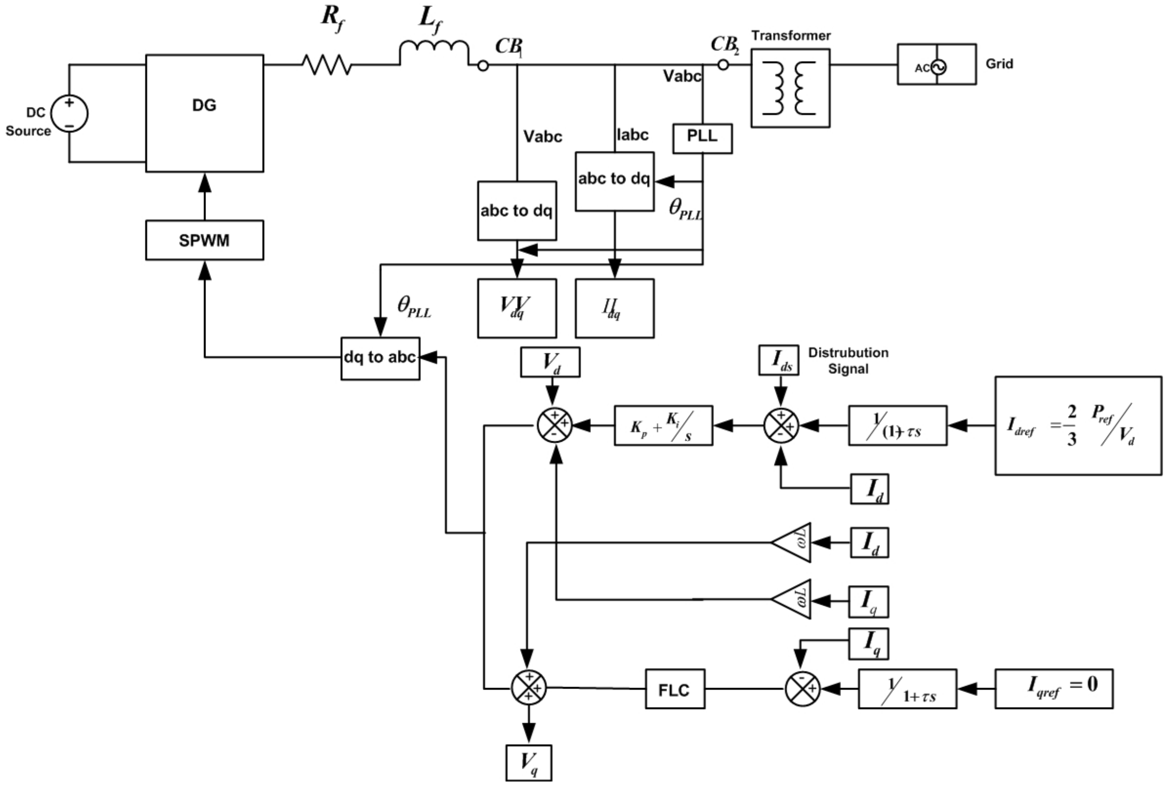

Figure 2. Control method used for the DG.

where, K represents the percentage of magnitude of the disturbance signal and ϖ_{ds} is the angular frequency of the disturbance signal in rad/s. As effect of this supplementary active fluctuating disturbance signal, the resultant current of the converter during grid coupled mode is expressed mathematically as,

$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \begin{bmatrix} I_d^* + I_{ds} \\ 0 \end{bmatrix} \quad (6)$$

where I_d, I_q, I_{d^*}, I_{ds} are d and q axis current of grid, d axis set point of current and disturbance signal respectively. The converter is operated at 1 power factor by feeding 0 q-axis current. By considering this operating mode, after islanding of main grid, the total output current of distributed generator is shared to parallel RLC load and the voltage at the point of common coupling is totally controlled by the mathematical equation as,

$$V_d = V_0 + V_1 \sin(\varpi_{ds} t + \phi_1) + V_2 \sin(\varpi_{ds} t + \phi_2) \quad (7)$$

where, V_d = Voltage at PCC, ϖ_{ds} = disturbance signal frequency

$$V_0 = RI_d^* \quad (8)$$

$$V_i = \frac{I_d \varpi_i L}{\sqrt[2]{\left(\frac{\varpi_i L}{R}\right)^2 + \left(\varpi_i^2 LC - 1\right)^2}}, \quad i = 1,2 \quad (9)$$

$$\phi_i = -\tan^{-1}\left[\frac{R\left(\varpi_i^2 LC - 1\right)}{\varpi_i L}\right], \quad i = 1,2 \quad (10)$$

$$\varpi_1 = (\varpi_0 - \varpi_{ds})\varpi_2 = (\varpi_0 + \varpi_{ds}) \quad (11)$$

Here, ϖ_0= fundamental frequency of the grid, R, L, C = load Resistance, inductance and capacitance respectively.

2.2 Introduction of active disturbance signal and harmonic analysis

During grid connected mode of operation, the current with fundamental frequency along with the disturbance signal flows into the grid. The obtained signal of d axis voltage of the converter as per,

$$V_{sd}(t) = V_d(t) - V_d(t - T) \quad (12)$$

Thereafter, two novel indexes are generated after islanding are: (a) Summation of accumulated values of V_{sd} over a fundamental cycle $V_{sd,cs}$ and (b) Rate of change of $V_{\acute{s}d,c}$. If these indexes increase above the threshold values then trip signal get generated after intentional delay of 20 ms shown in Fig. 3. This trip signal is used to operate the circuit breaker.

2.3 Introduction of fuzzy logic controller and ANFIS

The PI controller of the system can be replaced by fuzzy logic controller for better performance of the system. System have to face disturbances because the Performance of power system is non-linear in nature. Hence Fuzzy logic controller and ANFIS can be used to solve issues caused due to system non linearity's. The basic structure of FLC can be shown as in Fig. 4 (a), which shows mainly fuzzification, fuzzy interference and defuzzification. In fuzzification the two inputs are converted into fuzzy sets between [0, 1] with the help of membership functions.
An intelligent technique, ANFIS has demonstrated effectiveness in solving difficult system control, modelling, and

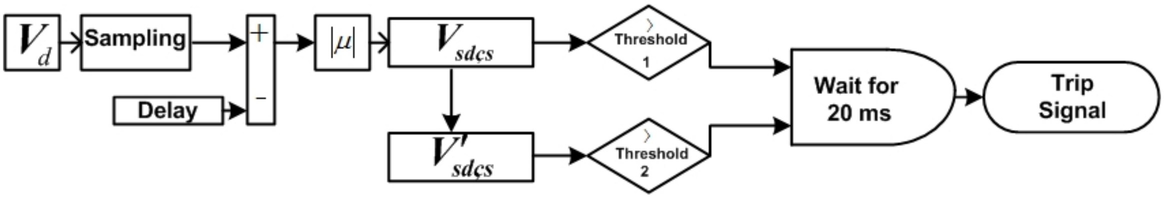

Figure 3. Anti islanding protection scheme.

classification challenges. Neural and fuzzy systems are combined in the right way to realize ANFIS. Using the back-propagation process, the premise parameters and consequent parameters are adjusted. The suggested neuro-fuzzy controller combines a five-layer artificial neural network (ANN) structure with a fuzzy logic algorithm. Here, the triangular membership function of five variables with overlap is utilized. The variables are as NB (Negative Big), NS (Negative Small), Z (Zero), PB (Positive Big) and PS (Positive Small).

3. Results and discussion

The CEGRE LV distribution system is used to observe efficacy of introduction of FLC and ANFIS for anti-islanding protection. Five DG sets and loads are connected to the secondary of transformer having rating of 20 kV/400 V, refer Fig. 5. And parameters are given in Table 1 and Table 2. Before islanding DGs are sharing power to grid and grid is feeding load, but after islanding DGs are sharing power to load. It is essential to detect islanding on earlier, and system should get stable earlier. Because due to injection

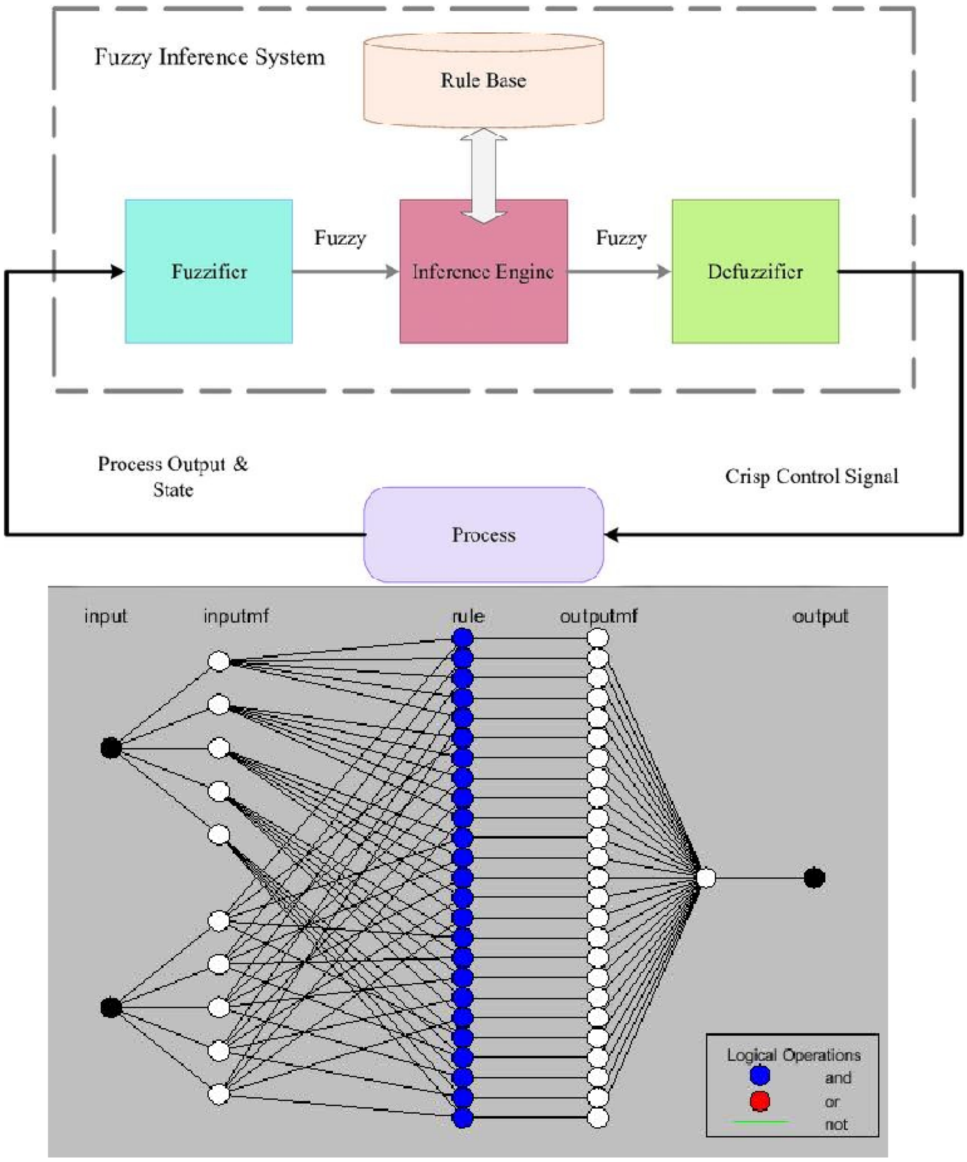

Figure 4. Methodology used for System. (a) structure of FLC, (b) structure of Rules of ANFIS.

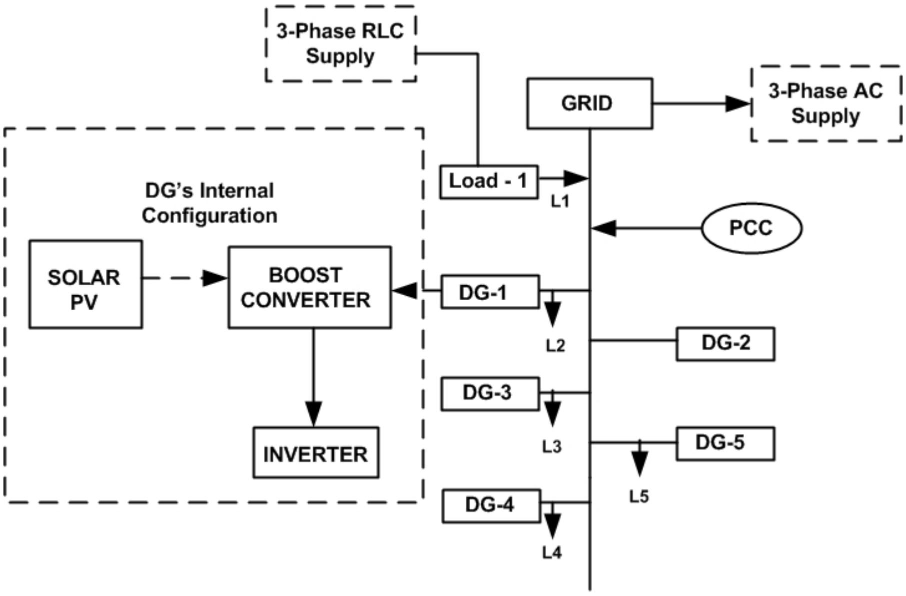

Figure 5. System Used for Analysis

Table 1. General details of the standard IEEE1547anti-islanding test system.

Specification	Value	Specification	Value
P_{DG}	5 kW	V_{dc}	700 V
Q_f	1	V_{grid}	400 V
L_f	10 mH	R	32 ohm
L	101.86 mH	C	99.47 microFarad
R_f	0.1 ohm	L_g	1 mH

P_{DG} = Real power supplied by DG. Q_f = Load Quality Factor. L_f = Inductance of filter. L = Inductance of Load. R_f = Resistance of filter. V_{dc} = dc link voltage. V_{grsid} = Grid Voltage. R = Resistance of Load. C = Capacitance of Load. L_g= Grid Inductance.

Table 2. Details of the controller.

Specification	Value	Specification	Value
K_{ppll}	50.3	K_{ipll}	5030
K_{pc}	10	K_{ic}	100
T	0.01	f_{PWM}	10 kHz

K_{ppll} = Proportional Gain of PLL. PLL = Phase Locked Loop. K_{pc} = Proportional Gain of Current Controller of DG. T = Time Constant. K_{ipll} = Integral Gain of PLL. K_{ic} = Integral Gain of Current Controller of DG. f_{PWM} = Switching Frequency of PWM. PWM = Pulse Width Modulation.

of disturbance in system, there are some stability issues. Implementation of FLC and ANFIS, helps to get trip signal earlier and make system stable.

3.1 Performance of system under zero power mismatch with PI controller

Zero power mismatch is considered as worst case scenario in the CEGRE *LV* distribution system to evaluate the dependability attribute of system. The five distributed generators are initially operated at unity power factor. The active disturbance introduced signal is synchronised with respect to a predetermined time manually at all instants of time. The loads are operated at the resonant frequency of 50 Hz, the quality factor of 1, and whole power generated by distributed generators is shared to loads.
By considering this condition, isolation of grid is started by operating the grid side circuit breaker and performance of protection method is shown in figure Fig. 6. d-axis voltage get oscillated when there is occurrence of islanding of part of grid, see in Fig. 7.
Islanding of grid is occurred at 0.5 s. PI controller shows sluggish response to the sudden disturbances in system. Hence it can be observed in Fig. 7 that the trip signal is generated after 0.56 s. After occurrence of islanding in system amplified disturbance signal is introduced in current controller loop as shown in Fig. 8. If the indexes $V_{sd,cs}$ and $V_{\acute{s}d,c}$ are found higher than their thresholds, the system generates high trip signal. The two signals of d-axis increase above the threshold value are 0.125 and 50 those can be observed in Fig. 9 and the trip signal get generated as shown in Fig. 7.
Although all the injected power are different, due to superimposition, all effects are cancelled and signal reaches the threshold value and system generates trip signal at 0.56 s. Signal get stable at 0.6 s.

3.2 Performance of system under zero power mismatch with FLC

The loads are operated at the resonant frequency of 50 Hz, the quality factor of 1, and the power generation of distributed generators is equal to the demand of the loads.
After islanding of main grid the circuit breaker get operated is shown in Fig. 11.
Here we can see that with using Fuzzy logic controller in

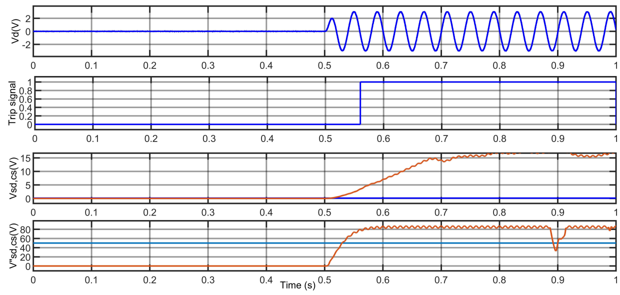

Figure 6. Zero power mismatch condition with PI controller.

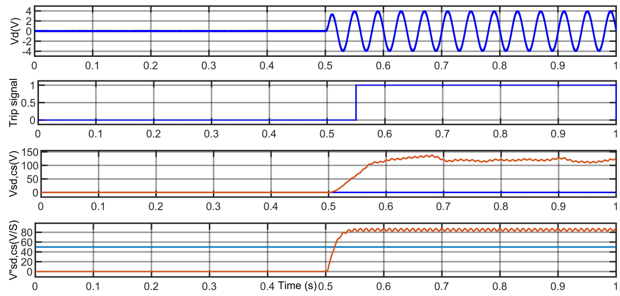

Figure 10. Zero power mismatch condition with FLC.

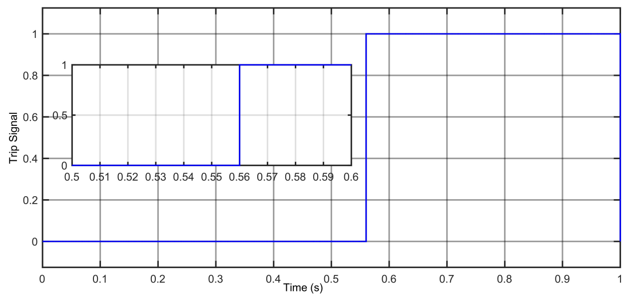

Figure 7. Trip signal with PI controller.

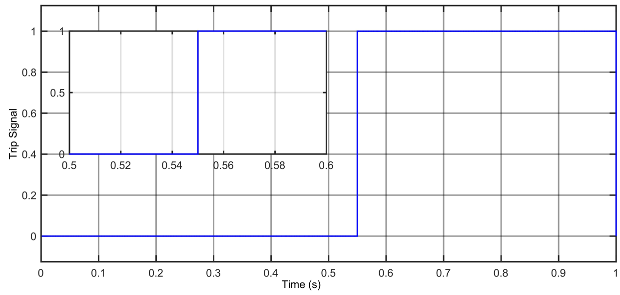

Figure 11. Trip signal generated with FLC.

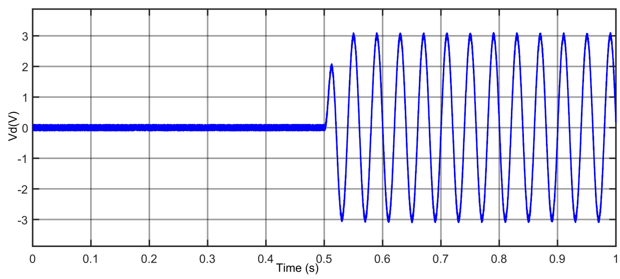

Figure 8. d-axis voltage showing Disturbance with PI controller.

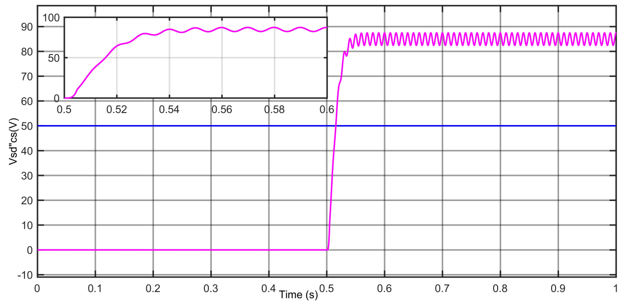

Figure 12. Rate of change of summation of disturbance signal with FLC.

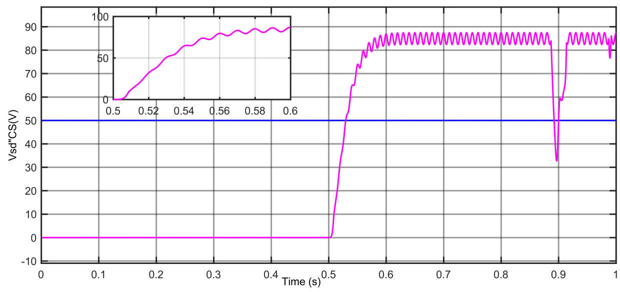

Figure 9. Rate of change of summation of disturbance signal with PI controller.

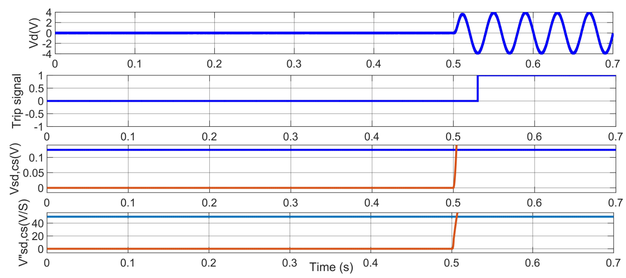

Figure 13. Zero power mismatch condition with ANFIS.

system, the system gives the trip signal earlier and also system come at steady state earlier as compared to PI controller. The threshold values are taken as 0.125 and 50, the trip signal will be generated when the signals exceeds these threshold values.

Fig. 10 shows that the system is having oscillation, it means there is occurrence of islanding of main grid. The active disturbance value will be zero for normal working condition and it does not affect on system performance but when the main grid get islanded then the V_d gets amplified. Which is helpful to increase the $V_{sd,cs}$ and $V_{\acute{s}d,c}$ to exceed the threshold value Fig. 12 and the trip signal is get generated at 0.55 s observe in Fig. 11. And system get stable at 0.54 s. Generated trip signal is used to operate circuit breaker. At this instant the DGs get disconnected from grid and it will share power to its local loads. But with the use of ANFIS the system get stable earlier as compared to FLC as shown in Fig. 15.

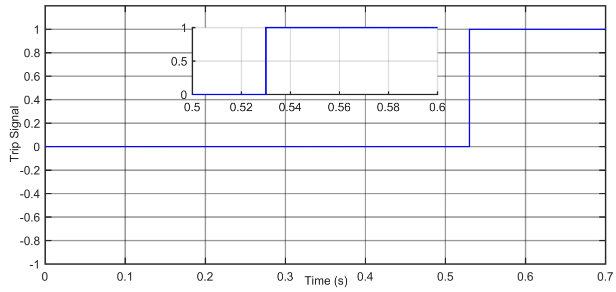

Figure 14. Trip signal generated with ANFIS.

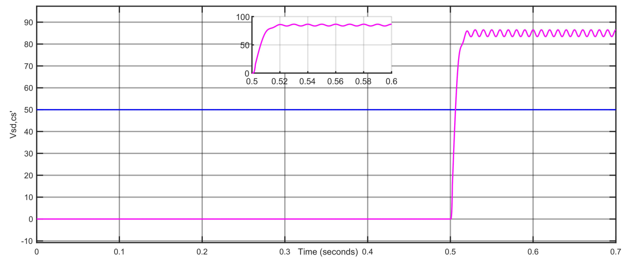

Figure 15. Rate of change of summation of disturbance signal with ANFIS.

3.3 Performance of system under zero power mismatch with ANFIS

Here, it can be observed that the system achieve trip signal earlier and the parameters comes to steady state on earlier as compared to PI and FLC, with use of ANFIS in system. The threshold values are taken as 0.125 and 50, the trip signal will be generated when the signals exceeds these threshold values. Fig. 13 shows that the PCC voltage V_d is having oscillation, it means there is occurrence of islanding of main grid. V_d gets amplified after islanding. Which is helpful to increase the $V_{sd,cs}$ to exceed the threshold value as shown in figures Fig. 15. And the trip signal is get generated at 0.53 s as shown in figure Fig. 14.
At the instant trip signal is generated, the distributed generators get disconnected from grid and it will share power to its local loads. As per observations and discussions, ANFIS is giving earlier trip signal as compared to PI controller and Fuzzy Logic Controller. ANFIS can be used for anti-islanding purpose with injection of active disturbance.

3.4 Harmonics reduction

Passive anti-islanding detection technique has large NDZ hence it is difficult to identify the islanding. The threshold has to be taken properly. If threshold is taken too small the unintentional tripping may occur and if it is enough large then the system may detect islanding.
Hence active anti-islanding detection method can be used. Active disturbance method has less NDZ but it affects on system adversely in the sense of power quality. It disturbs the power quality. It can be observed that the value of THD can be reduced with the use of Fuzzy Logic Controller and ANFIS as shown in Table 3.

3.5 Comments on result analysis

1) The trip signal get generated earlier in case of FLC as compared to PI controller it is at 0.56 s and for FLC its tripping at 0.55 s But ANFIS gives better result than PI and FLC, its tripping at 0.53 s.
2) System is becoming stable earlier for FLC as compared to PI controller, 0.6 s time is taken by PI controller and in case of FLC and ANFIS, it is become steady at 0.54 s.
3) The THD value is 8.64 for PI controller and it is reduced to 6.62 with the use of FLC, again it is reduced to 5.03 for ANFIS, comparison is shown in Table 3.
PI controller gives sluggish response as compared to ANFIS. It can be observed in Table 4. ANFIS is giving earlier response after islanding.

4. Conclusion

Anti-islanding study is necessary to protect grid being energized during its islanding condition. It is necessary to detect islanding condition earlier so that DGs will get disconnected from grid and will share power to local loads. NDZ plays an important role during islanding of grid. Where, active islanding methods gives less NDZ. Active disturbance signal is used for islanding detection. By analysing the system with PI controller, FLC (fuzzy logic controller), ANFIS (Adaptive network based fuzzy interference system). ANFIS (Adaptive network based fuzzy interference system) gives better results as compared to PI controller and FLC (fuzzy logic controller). Further

Table 3. Comparative analysis of ANFIS with PI, FLC and ANFIS.

Parameters	PI	FLC	ANFIS
Trip signal time (s)	0.56	0.55	0.53
System stable time (s)	0.6	0.54	0.54
% of THD considering voltage	8.64	6.62	5.03

Table 4. Comparative analysis of ANFIS with PI, FLC and ANFIS.

Parameters	PI	ANFIS
Speed of response	Sluggish	Fast
Duration of operation after islanding (s)	0.06	0.03
Duration of operation after islanding to get system stable (s)	0.1	0.04

trip signal can be achieved earlier by using type 2FLC.

Appendix
The supplementary data of the IEEE-14 and 30 bus systems is provided in another file, which is uploaded beside this manuscript.

Authors contributions
All authors have contributed equally to prepare the paper.

Availability of data and materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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