

HYBRID ANTI ISLANDING PROTECTION SCHEME FOR DISTRIBUTED GENERATORS BASED ON FUZZY LOGIC CONTROLLER

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Abstract

Distributed generators are blessing for power grid. Distributed generators should operate properly during and after islanding process. Here in this work the main focus is earlier islanding detection and to detect islanding on earlier. Hybrid islanding protection can be preferred for islanding detection. An active oscillatory disturbance is introduced in controller of the converter and fuzzy logic controller is used, so that the introduced signal gets amplified during islanding and it is helpful to detect the islanding. Generally proportional gain controller is used for islanding detection, but its response is slow, hence fuzzy logic controller is used. Fuzzy Logic controller gives earlier trip signal to system than proportional integral controller and small signal stability issues get improved. The system performance is discussed for zero power mismatch conditions. The simulation results of this proposed method is evaluated by using MATLAB Software.

Keywords: Boost Converter; Distributed Generator; Fuzzy Logic Controller; PI Controller; Sinusoidal Pulse Width Modulation; Solar - PV array; Transformer

Introduction

Now a days there is continuous increase in use of renewable energy sources (Mi and Wang, 2009). Due to large use of distributed energy resources there is also problem of unintentional islanding (IEEE draft standard, 2014). It is necessary to detect islanding and isolate distributed generator from power system earlier within 2 m (Noor *et al.*, 2005). The impacts of non-detection of unintentional islanding (Mukarram and Murkute, 2020) are given as: 1) Workers life risk due to live or energized lines. 2) Electrical parameters disturbance such as Voltage

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To minimize such issues, authors have discussed several methods (Arguence *et al.*, 2017) those are classified as: (a) Passive (b) Active and (c) Hybrid method. Passive anti islanding protection technique uses voltage and frequency monitoring relays (Raza *et al.*, 2015). Passive techniques

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(Hernandez *et al.*, 2006) are based on changes in system parameters like voltage and frequency to detect an unintended islanding. The disadvantage of passive methods is the crucial non detection zone (NDZ) as the microsource output power and demand power are nearly same.

Hence to solve this issue, the active anti-islanding protection techniques are suggested by authors (Dietmannsberger *et al.*, 2017). The LVRT capability is achieved in DGs using frequency deviation based active anti-islanding techniques (Wang and Freitas, 2008). In active anti islanding protection method, the disturbance signal is introduced through current controller of converter. It is necessary to study the effect of oscillatory disturbance signal introduction on system dynamics. Dynamics of the system get disturbed or violated due to use of positive feedback. (Karimi *et al.*, 2008; Reigosa *et al.*, 2015). The frequency of impedance is used to identify the islanding (Murugesan and Murali, 2020). There are some power quality issues are also occurring, so Hybrid anti islanding techniques are preferred (Murugesan and Murali, 2021).

A variable threshold based hybrid anti-islanding method has been discussed (Pigazo *et al.*, 2009; Kermany *et al.*, 2017; Nale *et al.*, 2019; Murugesan and Murali, 2020) for earlier detection of unintentional islanding. The active oscillatory disturbance injection technique are used for anti-islanding protection (Hoke *et al.*, 2018; Chaitanya *et al.*, 2021). The advanced techniques such as AI (Almas and Vanfretti, 2016; Grebla *et al.*, 2020) and DSP are used for anti - islanding protection algorithms. However, there are limitations are discussed as, 1) Heavy calculation load on the signal processors 2) Immense non detection zone 3) Large islanding detection time and 4) Variable thresholds are not practically easy (Kotaampopoulos *et al.*, 2018; Pal *et al.*, 2019; Ganivada and Jena, 2020).

In the power entity, the distributed networks are seemed to witness an uninterrupted raise in the DERs distributed energy resources. Nonetheless, one among the crucial issues that takes pace with considerably higher rate of energy resources of the renewable type is the unintended phenomenon of islanding. As per the IEEE 1547-2003 benchmark, an unintended occurrence of islanding must be identified and the distributed energy resources must be segregated from the entity well inside the two meters. The risks which are forced in the preventive measure of the personnel and general people because of not identifying the unintended islanding earlier could be asserted as below;

1. Unsteadiness of frequency and voltage of the localized islanded entity.

2. Risks to the maintaining person's safety in accordance to its lines that are energized.

Contributions is to conquer these disadvantages, a hybrid anti islanding protection strategy (Priyadarshi *et al.*, 2019) is developed. The oscillatory disturbance signal is introduced through the d-axis current controller of DG and time required to trip signal is noted also small signal stability analysis is performed. The d axis voltage (V) gives two new signals (Pal and Panigrahi, 2022) at the terminal of the distributed generators are then compared with befitting thresholds to identify an unintentional islanding case within 90 ms. Here in this work system performance can be improved with fuzzy logic controller. With FLC the islanding can be detected earlier (Tawanna *et al.*, 2019). Zero Power Mismatch is the dilemma situation 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. To ensure stability, the system must promptly detect islanding and trip the DGs. The FLC can generate a trip signal before the PI controller. Additionally, FLC damps signal oscillations earlier. The injection of disturbance signals into the current controller introduces harmonics into the system. However, FLC is able to effectively reduce the total THD. This work makes a valuable contribution by demonstrating that the implementation of FLC can significantly outperform the PI controller.

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.

Materials and Methods

This system configuration has been detailed in the following sections;

Control Mechanism used for the Distributed Generators

A standard IEEE 1547 anti-islanding test system is used to observe the impact of disturbance signal on system stability as well as the trip signal period as shown in Figure 1. The control mechanism used for DGs converter is shown in Figure 2. It is considered that the dc bus voltage remains constant. The mathematical expressions for the active and reactive power shared by the are given by,

Figure 2. Shows Control scheme used for Current Control Loop to inject disturbance signal

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

Here, V_d = Voltage at PCC, ω_{ds} = Disturbance signal frequency

Where,

$$V_0 = R I_d^* \quad (8)$$

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

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

Here, ω_0 = Fundamental Frequency of the grid, R, L, C = load Resistance, inductance and capacitance respectively,

$$\begin{aligned} \omega_1 &= (\omega_0 - \omega_{ds}) \\ \omega_2 &= (\omega_0 + \omega_{ds}) \end{aligned} \quad (11)$$

Here, ω_0 = Fundamental Frequency of the grid
 ω_{ds} = Disturbance signal frequency.

Discussion of Non Detection Zone

The active and reactive power mismatch equations are used for NDZ analysis. The equations are expressed as follows,

$$\frac{\Delta P}{P_{DG,0}} = \frac{P_{L,0}}{P_{DG,0}} - \frac{P_{DG}}{P_{DG,0}} \quad (12)$$

$$\frac{\Delta Q}{P_{DG,0}} = \frac{Q_{L,0}}{P_{DG,0}} - \frac{Q_{DG}}{P_{DG,0}} \quad (13)$$

Where P_{DG0} and Q_{DG0} are active and imaginary power shared by distributed generator before islanding, respectively. P_L and Q_L active and imaginary power drawn by the load, respectively, and ΔP and ΔQ indicates the real and imaginary power difference at the point of common coupling, respectively.

Two additional terms $V_1 \sin(\omega_{dst} + \alpha_1)$ and $V_2 \sin(\omega_{dst} + \alpha_2)$ generated after introduction of oscillatory active disturbance signal through the current controller of DGs converter. The mathematical equations of V_1 , V_2 , α_1 , and α_2 are the same as that of above expressions. Due to these two extra terms, the real power difference can never be zero. Hence this technique will give small NDZ. According to standard NDZ characteristics, the thresholds are (V [0.85, 1.15] pu and f [47.5, 52]). After application of quality factor of 1 and resonating frequency 50 Hz, the response of ΔP can be observed and it shows the significant NDZ due to active disturbance injection method. But there are some observable oscillations present. But still active disturbance method gives better performance than passive method.

Active Disturbance Signal Introduction and Total Harmonic Distortion

Fundamental component of current is available into grid as long as system is operating normal. The d-axis voltage of converter with fundamental frequency is,

$$V_{sd}(t) = V_d(t) - V_d(t-T) \quad (14)$$

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 $V_{sd,cs}$. If these indexes increase above the threshold values then trip signal get generated after intentional delay of 20 ms shown in Figure 3. This trip signal is used to operate the circuit breaker.

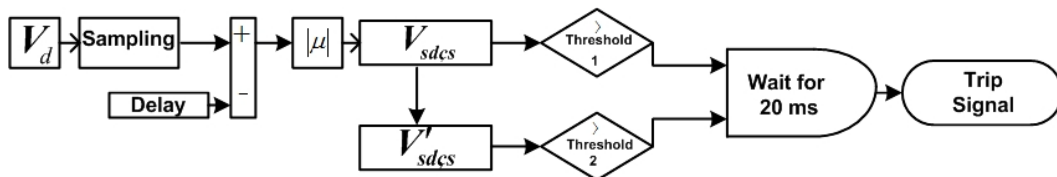


Figure 3. Shows Anti-Islanding Protection Scheme

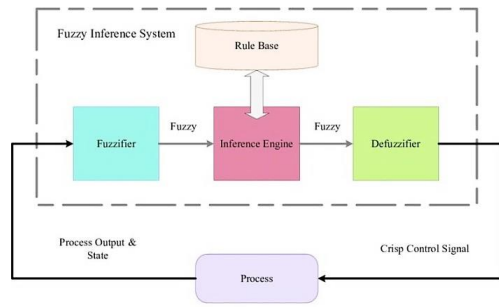


Figure 4. Shows Structure of FLC

Table 1. Shows General Details of the standard IEEE 1547 anti-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_{grid} = Grid Voltage; R = Resistance of Load; C = Capacitance of Load; L_g = Grid Inductance

Table 2. Shows 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

Introduction of Fuzzy Logic Controller

The PI controller of the system can be replaced by fuzzy logic controller for better performance of the system. The power system is nonlinear in characteristics and subject to network disturbances therefore FLC can be used to deal with system non linearity's. The basic structure of FLC can be shown as in Figure 4, which shows mainly fuzzification, fuzzy inference and defuzzification. In fuzzification the two inputs are converted into fuzzy sets between [0, 1] with the help of membership functions.

In this study the triangular membership function including overlap is used and it is composed of five variables. The variables are as NB (Negative Big), NS (Negative Small), Z (Zero), PB (Positive Big) and PS (Positive Small).

ANFIS, an intelligent technique, has proven effective in addressing complex system control, modeling, and classification difficulties. Neural and fuzzy systems must properly couple to achieve

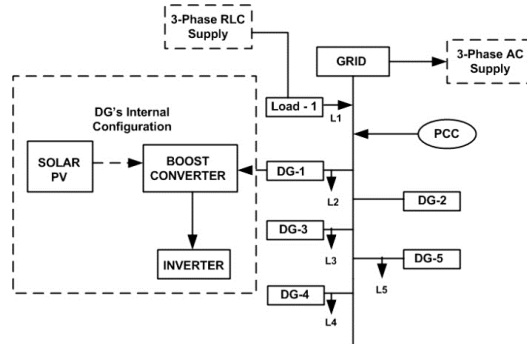


Figure 5. Shows Suggested System for Analysis

ANFIS. We use back-propagation to modify the premise and subsequent parameters. The proposed neuro-fuzzy controller integrates a five layer artificial neural network (ANN) with a fuzzy logic algorithm.

Results and Discussion

The CEGRE LV system is analyzed with PI controller and Fuzzy Logic Controller (FLC). The system is simulated considering the thesaurus situation. Five DG sets are connected to distribution system. The DGs are connected at the secondary of transformer having rating of 20 kV/400 V. DGs are sharing power to main grid and loads are feeded through grid. After islanding of main grid, the DGs will feed power to load. It is necessary to detect islanding earlier and system should come to steady state earlier. DG1 and DG2 will generate power of 30 kW, DG3 generate power of 20 kW, DG4 and DG5 generates power of 10 kW respectively refer Figure 5. The general details of the system and the controller are given in Tables 1 and 2.

Zero Power Mismatch Condition with PI controller

The effectiveness of suggested anti-islanding protection method is assessed by using the CEGRE LV distribution test system. To evaluate zero power mismatch condition; distributed generators are operated at unity power factor, The oscillatory disturbance signal is aligned along the predefined time. The system is tuned at the resonant frequency of 50 Hz, the quality factor of 1, and DGs are sharing power which is required by loads. By considering this situation, circuit breaker will open and islanding will occur is shown in Figure 6.

In Figure 6, it can be observed that the d-axis gives the oscillation when there is occurrence of islanding of part of grid. If the indexes $V_{sd,cs}$ and $V_{s'd,cs}$ 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 Figure 8 and the trip signal get generated as shown in Figure 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 Figure 7 that the trip signal is generated after 0.56 s. Figure 8 shows that the system is showing slower response. After exceeding value of $V_{sd,cs}$ above threshold value trip signal is generated.

Although, all the power injected are different, due to superimposition, all effects are cancelled and signal reaches the threshold value and system generates trip signal.

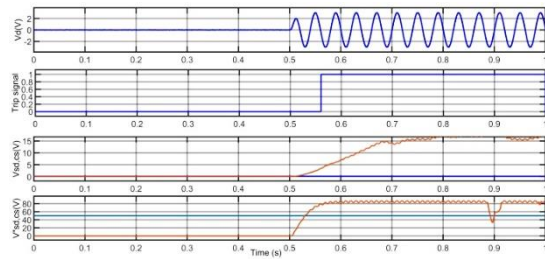


Figure 6. Shows Performance of system with zero power mismatch condition with PI controller

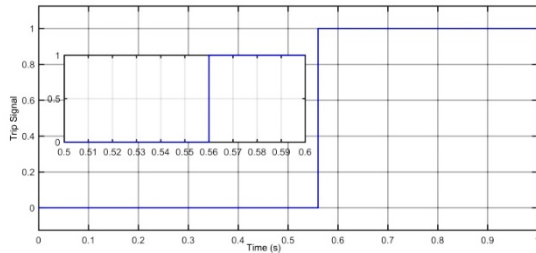


Figure 7. Shows Trip Signal with PI Controller

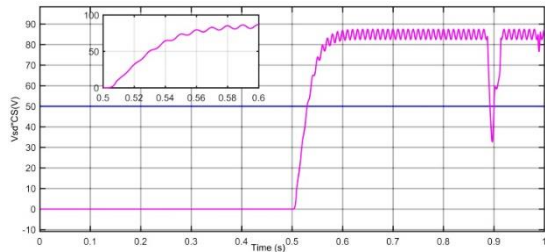


Figure 8. Shows Rate of change of Summation of Disturbance signal with PI Controller

Zero Power Mismatch Condition with FLC

The system is operated at the resonant frequency of 50 Hz, the quality factor of 1, and DGs are sharing power which is required by loads. By considering this situation, circuit breaker will open and islanding will occur and performance of protection scheme is shown in Figure 9. Here we can

see that with using Fuzzy logic controller in 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.

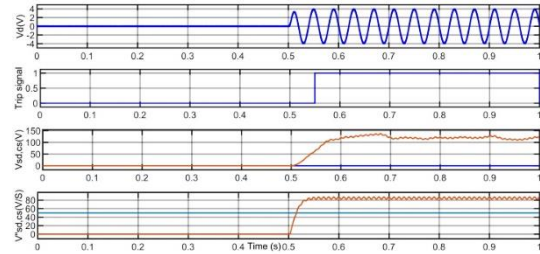


Figure 9. Shows Performance of system with zero power mismatch condition with FLC

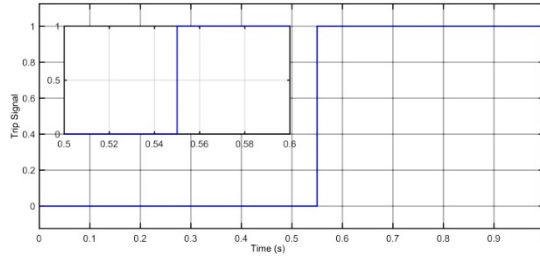


Figure 10. Shows Trip Signal Generated with FLC

Figure 9 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 $V_{sd,cs}$ to exceed the threshold value Figure 11 and the trip signal is get generated Figure 10.

Trip signal is given to circuit breaker. At this instant the DGs get disconnected from grid and it will share power to its local loads. At that instant there are observable oscillations in signal Figure 11. But the system is becoming stable earlier in case of FLC.

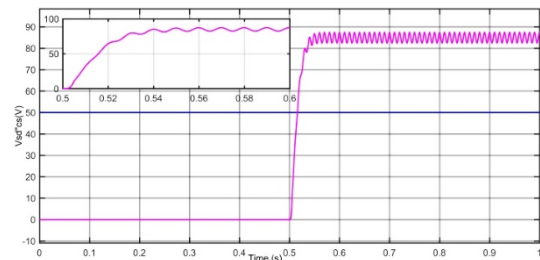


Figure 11. Shows Rate of change of Summation of Disturbance signal with FLC

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 then unintentional tripping may occur and if it is too large then the system may detect islanding. Hence Active anti-islanding detection method can be used. Here active disturbance injection method is 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 shown in Table 3.

Table 3. Shows Comparative analysis with PI and FLC controller

Parameter	PI	FLC
Trip Signal Time(s)	0.56	0.55
System Stable Time(s)	0.6	0.54
Percentage of THD considering Voltage	8.64	6.62

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 for PI and for FLC its tripping at 0.55 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 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, comparison is shown in Table 3.

Conclusion

While working with the integration of distributed generators with main power grid, it is necessary to protect grid being energized during islanding condition. Hence is essential to detect islanding as earlier as possible and fulfill the demand of local loads. Non detection zone is the most important aspect in case of active and passive anti islanding detection methods. Active method gives small NDZ in both of them. By comparing the results of PI controller and FLC, FLC gives better results as compared to PI controller. Further trip signal can be achieved earlier by using ANFIS and Type 2 FLC.

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