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Determining the Necessity and Timing of Controlled Islanding in Power System: a wide-area intelligent-based method

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ABSTRACT

The present study introduces a new extensive-area ANFIS (Adaptive Neuro-Fuzzy Interface System)-based method to detect wide area instability and control the time of controlled islanding execution within power systems. The ANFIS parameters are optimized by the PSO method to increase the method's accuracy at various disturbances and loading circumstances. In addition, to take various stability margins within the areas into account, a novel parallel ANFIS network (P-ANFIS) is implemented in which a distinct ANFIS is allocated for every nearby area. Extended off-line studies are performed to train ANFIS to respond in real-time accurately based on the selected wide area input signals. These parameters are monitored continuously through a wide area measurement system (WAMS) and the proposed P-ANFIS starts to assess the stability between related areas in real-time in the case of potentially unstable oscillations. Once an unstable oscillation is detected, the islanding command is transmitted to perform the controlled islanding scheme. The suggested technique is used in an IEEE 39 bus power system and its performance is demonstrated at different disturbances in terms of both speed and accuracy. It is found that the suggested ANFIS-based technique can determine islanding requirement and its time of execution properly at different disturbances.

Article Info

Keywords:
ANFIS, Islanding detection, PSO, WAMS

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NOMENCLATURE

δ_i	Rotor angle of generator *i*
δ_j	Rotor angle of generator *j*
x_i	*i*th particle
pbesti	the best former position of x_i
gbest	is the best particle between the whole population
$t^{initials}$	the time of simulation starting in transient stability studies
t^{final}	the time of simulation ending in transient stability studies
μ	Threshold value for coherency determination between generators
$\mu_{A_j^i}(x)$	Membership function for the ith input variable
$\Delta\bar{\delta}_{\mathrm{COI}_{m,n}}$	difference of the center-of-inertia (COI) of rotor angles of two preliminary areas
N_t	number of units in area *m*
N_k	number of units in area *n*
M_t	total inertia of *t*th group based on N_j generators
$\Delta\bar{\theta}_{m,n}$	Difference of the average voltage angles between two areas *m* and *n*
θ_i	Buses' voltage angles in group *m*
θ_j	Buses' voltage angles in group *n*
$\Delta\bar{\omega}_{m,n}$	Average frequency difference between two areas *m* and *n*

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I. INTRODUCTION

Wide-area asynchronous oscillations and local distance operations relay in response to these oscillations is the main reason for some recent blackouts [1-2]. These oscillations are propagated in the power system from the initial happening location and could result in the initiation of a cascade outage and considerable power outages [3-4]. The controlled islanding application is the last resort protective scheme in power systems to stop disturbance propagation and avoid wide-area blackouts [5]. One of the main parts of controlled islanding is its necessity and execution time [6]. The controlled islanding should be performed correctly to avoid unnecessary disconnection of lines between areas. In addition, the islanding command should be sent fast once unstable oscillations between areas are detected [7]. The conventional way to this action is the installation of local R-Rdot relays in predetermined interconnected lines to act once unstable oscillations are detected. But, the performance of these local relays at different scenarios and network structures is not satisfactory because of the offline setting and anticipated oscillations in power systems.

A decision tree (DT) is introduced in [8] to detect wide-area instability and send arming signals to the installed local relays. By this method, the unwanted operation of these local relays is avoided and islanding execution can be performed at proper locations. The coherent areas of the network are determined offline and different DTs are assigned to each of them for stability assessment. In this method, the confidence level of different DTs is investigated and a final decision is made based on the outputs of different DTs.

In [9], a neural network technique is used to detect islanding requirements. The recurrent neural network is trained offline to detect and send the islanding command in the case of unstable oscillations. The Lyapunov Maximal Exponent (LME) method is another wide area-based method for real-time stability assessment and the determination of asynchronous oscillations based on WAMS data [10]. The positive LME value represents the loss of generators' synchronism within the network. However, as mentioned in [11], the performance of this method is highly dependent on the selected input data time interval and the algorithm applied for LME computation. It should be indicated that the islanding detection technique could distinguish between inter-area and local oscillations and respond only to the latter [12-13].

In [14], controlled islanding time is determined by using new indices. In this method, by applying the concept of inertia for coherent generators and modeling two oscillating areas with a Generalized Single Machine Infinite Bus System (GSMIB) model, an equivalent power-angle curve is derived from which equivalent Unstable Equilibrium Point (UEP) point associated with the inter-area oscillation is evaluated. The curve is, then, used to derive new instability indices associated with inter-area oscillation. In [15], a splitting strategy is developed as an MILP problem considering coherency and frequency stability constraints. A switching constraint and a frequency stability

constraint are proposed to limit the number of line switchings and assure the stability of the resulted islands, respectively. The switching constraint proposed in this paper reduces the searching space of splitting strategies and the Benders Decomposition (BD)-based algorithm shortens the calculation time.

In [16], a straightforward multi-solution approach is proposed in which a hierarchical spectral clustering algorithm is used. Its power system islanding algorithm is based on the minimum active power flow disruption approach. The most convenient islanding scenario can be selected by a desired secondary objective function to satisfy the operational requirements. The proposed algorithm is based on an improved hierarchical clustering theory to have the ability to accompany the generator coherency constraint in the clustering process. In [17], by analyzing the voltage frequency characteristics of an electrical center and a non-electrical center at different voltage amplitude ratios for the out-of-step condition of the power grid, an out-of-step splitting criterion based on bus voltage frequency is presented.

In this study, a novel extensive-area intelligent scheme is constructed based on the ANFIS algorithm for detecting controlled islanding necessity and its execution time fast and accurately. The power system is split into different initial coherent areas based on offline stability works at various loading conditions and disturbances. Any of these initial areas could be separated and form inherent stable islands based on the location of disturbances or could be aggregated together and form larger stable islands. The network oscillations are monitored continuously after disturbance occurrence and final coherency is determined in real-time on the basis of WAMS data. The distinct ANFIS is allocated to each nearby initial area for stability investigation optimized by the PSO method. As an unstable inter-area oscillation is found by the proposed technique and the islanding command is sent, the related areas are separated as soon as possible. A comparison is also made for the proposed intelligent method's performance and the ANN method [9] in an IEEE 39-bus power system at two various cases.

I. CONTROLLED ISLANDING TIMING

The islanding execution time is a key element to obtain a reliable and effective controlled islanding structure within large interconnected power systems [7]. As a result of asynchronous inter-area oscillations, the network needs to be divided into stable islands prior to the uncontrolled separation

of the network. Figure 1 presents the proposed algorithm's flowchart for determining the real islanding execution time. In this algorithm, WAMS measurement plays a critical role in providing wide-area information to the algorithm. Like [9], to have an adaptive and fast scheme in real-time, many actions should be performed in offline and online steps. These actions are explained in the following sections.

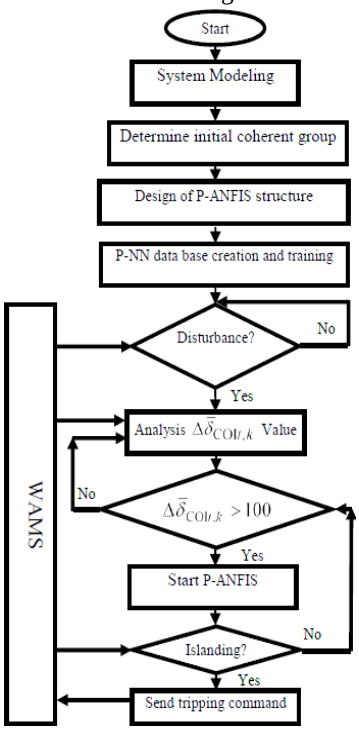


Fig. 1. The flowchart of the proposed scheme

II. Offline Actions

The main procedures in the offline part tend to increase the speed and accuracy of islanding detection. As shown in the following sections, these steps include system modeling, the determination of initial areas, and ANFIS training.

A. System modeling

System modeling consists of two steps, i.e., static and dynamic modeling. In addition to static data such as the nominal voltages of buses, the length of lines, the capacity of transformers, impedances, and load values, the dynamic data of the studied power system such as the parameters of generators, AVRs, and governors are modeled.

B. Determination of initial areas

The coherency of generators is altered based on the disturbance location and network structure. In this step, the initial areas consisting of coherent generators at different conditions are determined based on offline studies. The coherency of the generators in these initial areas is kept at different loading conditions and disturbances in interconnected lines. The final coherent areas following different disturbances are determined in real time based on the COI of rotor angle between adjacent initial areas.

To determine the initial coherency, the criteria are used as shown in (1). The parameters δ_i and δ_k indicate the rotor angle of generators i and k, respectively. The value of 120 degrees is applied for μ and the total time of simulation is selected to be 10 seconds.

$$\left|\delta_i(t) - \delta_k(t)\right| \le \mu \qquad t^{initial} \le t \le t^{final} \tag{1}$$

This study is performed at three different loading conditions including the outage of network elements following different disturbance locations.

The output of this step is potential islands whose generators are stable and could be merged with stable adjacent areas to form larger islands with respect to disturbances and network configuration.

III. The Proposed P-ANFIS Structure

As mentioned in [12] and is derived by offline stability, the stability margins between adjacent areas are different based on the loading circumstances and their connections before and after disturbances. The stability margins are higher for highly meshed areas than for weaker interconnected areas. These differences could not be accounted for by the single ANFIS structure with inputs from all of the areas. Therefore, the new parallel ANFIS (P-ANFIS) is constructed (Fig. 2). At this scheme, a distinct ANFIS is allocated for each of the two nearby primary groups that are responsible for investigating the stability between them in real-time. Each ANFIS of P-ANFIS is trained separately with proper related wide-area inputs.

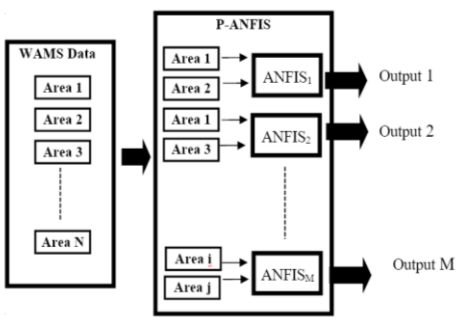


Fig. 2. The planned P-ANFIS structure

A. Individual ANFIS structure

The ANFIS structure used here is a 3-structure type with five different layers as shown in Fig. 3 [18]. Considering a first-order Sugeno fuzzy model possessing one output and two inputs, the rules are organized as follows:

First rule: If x is A_1 and y is B_1, then $f_1 = p_1x + q_1y + r_1$

Second rule: If x is A_2 and y is B_2, then $f_2 = p_2x + q_2y + r_2$

The Gaussian membership functions are utilized for input

and output variables. Therefore, the *j*th membership function for the *i*th input variable is [19]:

$$\mu_{A_j^i}(x) = exp(-(\frac{x_i - c_i^j}{a_i^j})^2) \quad (2)$$

where ai and ci denote the width and center of the associated membership function, respectively.

Layer 1: Here, every node i represents a square node with a node function of:

$$O_i^1 = \mu_{A_i}(x) \quad (3)$$

in which *x* denotes the input to node *i* and *A* represents the linguistic label (small and large) connected to this node function.

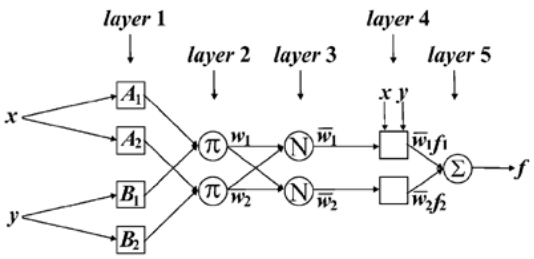


Fig. 3. The ANFIS 3-structure type

Second layer: The output is the product of all arriving signals. Here, every output node provides a rule's firing strength.

$$O_i^2 = \omega_i = \mu_{A_i}(x).\mu_{B_i}(y) \quad ,i = 1,2 \quad (4)$$

Layer 3: Here, the outputs, termed the normalized firing strengths, are determined as follows:

$$O_i^3 = \bar{\omega}_i = \frac{\omega_i}{\omega_1 + \omega_2} \quad ,i = 1,2 \quad (5)$$

Layer 4: This layer's node function is:

$$O_i^4 = \bar{\omega}_i\ f_i = \bar{\omega}_i\,(p_i x + q_i y + r_i) \quad (6)$$

The elements of the parameter set are determined as the consequent parameters, $\{p_i, q_i, r_i\}$.

Fifth layer: The general output is determined as the sum of all incoming signals through the following equation.

$$O_i^5 = \sum_i \bar{\omega}_i\ f_i = \frac{\sum_i \omega_i\ f_i}{\sum \omega_i} \quad (7)$$

As mentioned in [19], these two parameters are much effective in ANFIS performance and there is no straightforward procedure for their determination. Therefore, the PSO is used in this paper to optimally determine these two parameters.

B. Particle swarm optimization

Particle Swarm Optimization (PSO) is a population-based search algorithm that was first presented by Eberhart and Kennedy and is extensively used to solve numerous optimization problems [20]. As shown in [21], the optimization procedure can be classified into 6 steps from the initialization step to the output result, which gives the best solution within the optimization procedure. The updating rules for the PSO algorithm are as follows:

$$v_i^{k+1} = w.v_i^k + c_1 \cdot rand_1(x_{pbesti} - x_i^k) + c_2 \cdot rand_2(x_{gbest} - x_i^k) \quad (7)$$

$$x_i^{k+1} = x_i^k + v_i^k \quad (8)$$

in which c_1 and c_2 denote the positive constants (as acceleration coefficients), *w* represents inertia weight factor, $rand_1$ and $rand_2$ denote random functions ranging in [0,1], x_i denotes the *i*th particle, $pbest_i$ is the best former position of x_i, and *gbest* represents the best particle between the whole population. The parameter v_i is the velocity of particle x_i.

C. Hybrid learning by PSO and GD

The conventional way for ANFIS training including the backward and forward passes is the combination of both the backpropagation gradient descent algorithm and least-squares estimator. However, in this paper, the PSO and gradient descent are applied in ANFIS parameters updating in ANFIS training. The antecedent part with Gaussian membership function parameters including $\{a_i, c_i\}$ is updated through PSO while the gradient descent is used for updating conclusion parameters such as $\{p_i, q_i, r_i\}$ [22].

D. P-ANFIS inputs -outputs

The following three parameters are selected as the P-ANFIS inputs that are measured by WAMS. The first parameter is shown in (8).

$$\Delta\bar{\delta}_{\mathrm{COI}_{m,n}} = (\frac{1}{M_t}\sum_{i=1}^{N_t} M_i\delta_i - \frac{1}{M_k}\sum_{i=1}^{N_k} M_i\delta_i) \quad (9)$$

$$, M_t = \sum_{i=1}^{N_j} M_i$$

in which $\Delta\bar{\delta}_{\mathrm{COI}_{m,n}}$ represents the differences in the COI (center-of-inertia) of the rotor angles between two adjacent determined initial areas, N_t and N_k denote the number of generators in two areas *m* and *n*, and M_t represents the total inertia of the *t*th group. In addition to the signal presented in (8), another input signal is:

$$\Delta\bar{\theta}_{m,n} = (\frac{1}{N}\sum_{i=1}^{N}\theta_i - \frac{1}{M}\sum_{j=1}^{M}\theta_j) \quad (10)$$

In (8), the voltage angles between two areas *m* and *n* are averaged and their difference is used as the input. θ_i and θ_j denote the buses' voltage angles at two areas *m* and *n* with *N* and *M* PMUs. The average frequency difference ($\Delta\bar{\omega}_{t,k}$) is:

$$\Delta\overline{\omega}_{m,n} = \frac{d\Delta\overline{\theta}_{m,n}}{dt} \quad (11)$$

The ANN inputs are the chosen signals in (8) to (10) and their five delayed values. The ANN's output is supposed as 0 for stable cases and 1 for unstable cases.

E. P-ANFIS Database

A systematic approach is designed to create a proper database for ANFIS training based on comprehensive offline stability studies. To do this, the following operating conditions are investigated:

1-Three different loading conditions of the network

2-Considering the outage of elements in three different loading conditions

After constructing the above-mentioned operating conditions, the following systematic method is used at various network structures and loading circumstances:

Step 1: Three-phase and single-phase fault is used at various positions of the network with normal fault clearing time corresponding to the main protection relays.

Step 2: The fault clearing is increased to the corresponding time of back-up relays to consider the failure of the main protection systems.

Step 3: The second disturbance at different locations is applied following the first disturbance prior to the operations of the present corrective actions.

The generated data set containing input-output pairs is used to train every ANFIS in the proposed P-ANFIS.

IV. On-line Actions

Two main actions are performed online including (i) disturbance detection and (ii) continuous monitoring of $\Delta\overline{\delta}_{\mathrm{COI}_{t,k}}$ after disturbance detection. The method proposed in [23-25] is used for disturbance occurrence in a power system based on monitoring both voltage magnitude and its rate of changes of generator buses with time. As the disturbance is detected, the signal introduced in (8) based on the COI-referred angle of each area is computed and fed continuously to the algorithm. By investigation of $\Delta\overline{\delta}_{\mathrm{COI}_{t,k}}$, the possible angle separation between areas is predicted. If the $\Delta\overline{\delta}_{\mathrm{COI}_{t,k}}$ value between any of the areas becomes larger than 100 degrees, the alarm signal is sent to the P-ANFIS to assess the network stability in real-time based on the input data from WAMS.

V. Real-time Actions

The P-ANFIS assessed the stability between every nearby area that has a distinct ANFIS trained offline with proper inter-area-based signals that are measured through WAMS. As unstable inter-area oscillations are detected, (Output=O=1), the tripping signal is sent through WAMS to the P-ANFIS. To detect the asynchronous oscillations (output=*Y*=1) by every individual NNs, the tripping signal is sent via WAMPAC to separate the associated areas from each other. While the $\Delta\overline{\delta}_{\mathrm{COI}_{t,k}}$ values between areas become less than 100 degrees and remain for 5 seconds less than 100, the P-ANFIS analysis is stopped and wait for the next possible alarm to start stability assessment.

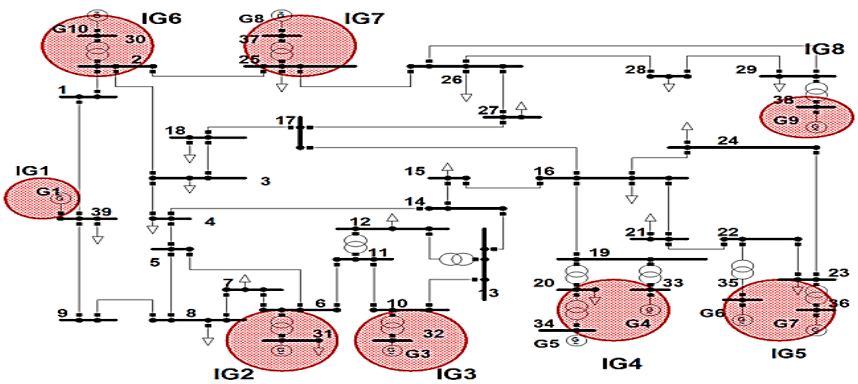


Fig. 4. The New England 39-bus and defined primary groups

VI. Simulation Results

The behavior of the suggested P-ANFIS algorithm is assessed on a New England 39-bus power system.

A. The New England 39-bus system

Figure 4 presents the single line chart of the New England 39-bus power system [26]. The initial areas determined offline are shown in Fig. 4 and agree with the FC-Mdd method applied in [9]. Here, two various cases are taken into account to represent the efficiency of the designed P-ANFIS structure. The performance of the proposed method is investigated with the proposed ANN technique [9].

B. Case study 1

The faults applied in this case are as follows:

A three-phase fault is applied in lines 9-39 at 0.1s and is cleared 0.3s later by the outage of the line. Moreover, another fault occurs in 0.5s in lines 4-5 and is removed 0.2s later by line breakers. The rotor angle oscillation of generators is shown in Fig. 5. As can be seen, the network stability is lost following these disturbances. Three different coherent groups are identified and it is necessary to apply network islanding to avoid the wide-area blackout. The voltage magnitude of generator buses as a disturbance indicator is shown in Fig. 6. After the detection of disturbance occurrence, monitoring of $\Delta\bar{\delta}_{\mathrm{COI}_{t,k}}$ between initially determined areas is started by the proposed algorithm. As the $\Delta\bar{\delta}_{\mathrm{COI}_{t,k}}$ value between each of the areas exceeds the threshold value (100 degrees), the P-ANFIS starts stability assessment based on wide-area input signals.

Fig. 7 represents the $\Delta\bar{\delta}_{\mathrm{COI}_{t,k}}$ values between some of the initial areas. The $\Delta\bar{\delta}_{\mathrm{COI}_{t,k}}$ values between IG1 and two of its adjacent areas (IG2 and IG6) in Fig. 4 are increased continuously after the first disturbance. Therefore, IG1 swings separately and should be split from the network. By investigating Fig. 7, the network should be split into three following islands that are in agreement with Fig. 5:

Area 1 (island1), Area2-Area3 (island2) and Area4-Area8 (island3)

The outputs of the proposed P-ANFIS method optimized with PSO should be analyzed to investigate the performance of the suggested technique in correct islanding detection. The outputs of some ANFISs are shown in Fig. 8.

According to this figure, the output of ANFIS 1, which is responsible for stability assessment between areas 1 and 6, becomes unity earlier than other output indicating that area 1 should be separated from area 6, which is a correct decision

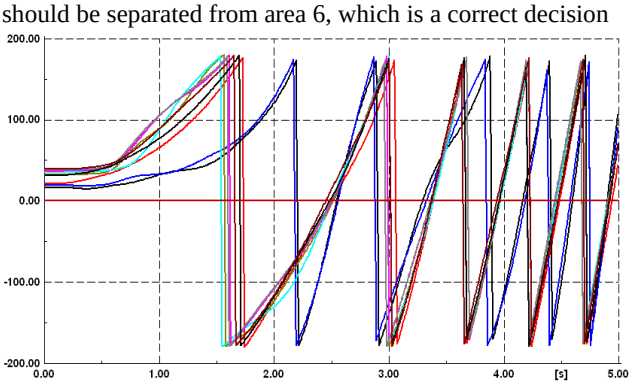


Fig. 5. rotor angle oscillation of generators in case

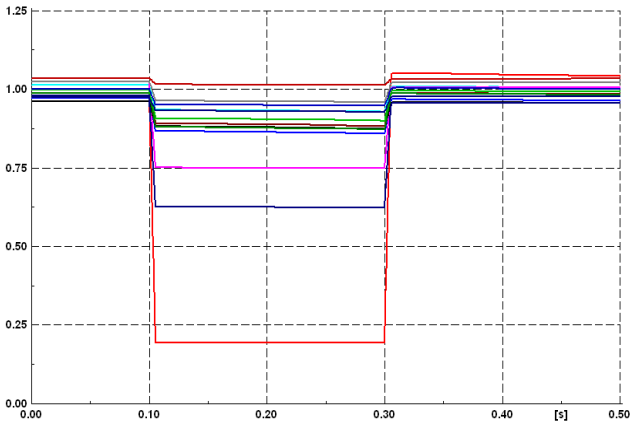


Fig. 6. The voltage magnitude of the generator

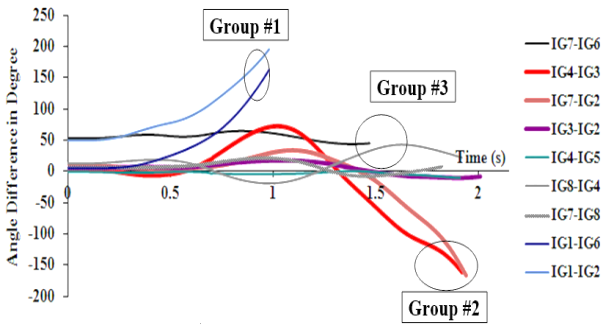


Fig .7. $\Delta\bar{\delta}_{\mathrm{COI}_{t,k}}$ between some initial areas in the 39-bus network at case1

In addition, the output of ANFIS 5 becomes near to unity (0.999) in 1.4 s, indicating that area 3 should be separated from area 4 that is a correct decision according to Fig. 7. As shown in Fig. 8, the outputs of assigned ANFISs between stable areas are too low and therefore the islanding command is not sent between these areas. The outputs of ANFIS 11 (area 8-area4) and ANFIS 7 (area 2-area3) are low as shown in this figure, indicating that these areas are coherent groups.

As shown in Table I, the islanding command is sent earlier by the proposed optimized P-ANFIS method than actual angle separation with enough margins to apply proper corrective actions. The time of islanding command to separate area 1 from area 6 is sent in 0.66 s, which is actually 0.38s before actual instability.

The outputs of some proposed ANFISs are provided in Tables II and III and are demonstrated with the ANN [9] and proposed ANFIS method in [12] where, there is no PSO application. According to these results, the stability/instability between areas is predicted with high accuracy before their actual uncontrolled separation that gives the proper time to perform a controlled islanding scheme. In addition, in comparison with both of the ANN and ANFIS method, the islanding necessity is predicted earlier between areas by proposed optimized ANFIS with PSO as shown in Tables II and III. This early detection gives more time to avoid

instability in coherent areas.

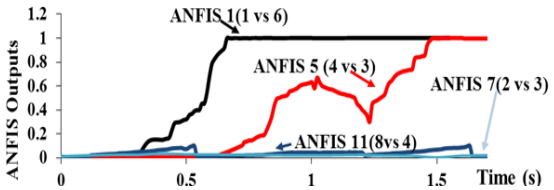


Fig.8. outputs of some optimized ANFISs with PSO in the P-ANFIS structure

C. Case study 2

The following faults are applied in this case:

A three-phase fault is applied in 0.1s in line 1-39 and is cleared in 0.3s by line breakers. The second fault is occurred in 0.5s and is cleared in 0.7s by opening the faulted line. $\Delta\bar{\delta}_{\mathrm{COI}_{t,k}}$ between areas in this case are presented in Fig. 9. A look at Fig. 9 indicates that the network should be split into three following coherent islands in that the areas belonged to each island are different from those in case 1:

Area 1 (island1), Area2-Area3 and Area6-Area8 (island2), Area4-Area5 (island 3)

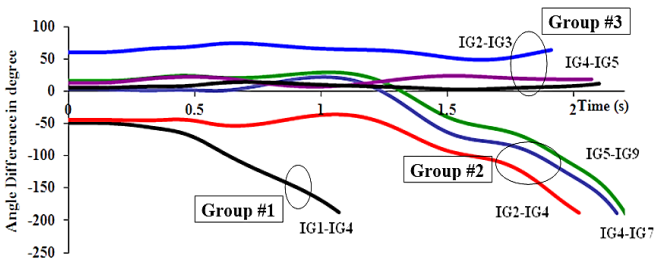


Fig. 9. $\Delta\bar{\delta}_{\mathrm{COI}_{t,k}}$ between some areas in case 2 at the 39-bus network

The outputs of some ANFISs are shown in Fig. 10. The early and correct detection of islanding necessity by P-ANFIS outputs are evident with the comparison of Figs. 9 and 10. According to Fig. 10, the islanding command is sent to separate area 2 from area 4 as a correct decision. The islanding command is sent in 1.42s, and the actual angle separation between these two IGs happens in 1.83s. The outputs of the proposed P-ANFISs are given in Tables IV and V and are demonstrated with other two methods including ANN and ANFIS without PSO application.

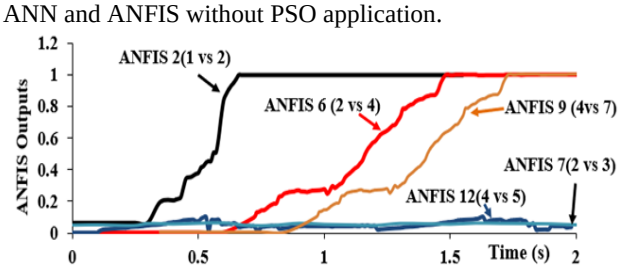


Fig. 10. The outputs of some optimized ANFISs with PSO in the P-ANFIS structure

By comparing the proposed method with the ANN results (Table IV), the P-ANFIS shows a more accurate and faster response than the ANN method. Like previous case, as shown in Table V, the performance of the proposed optimized ANFIS parameters with PSO is faster than applied ANFIS method in [12].

Therefore, there is enough time to conduct islanding and split the network into coherent stable islands.

VII. CONCLUSION

In this study, a novel extensive-area intelligent technique is introduced to accurately and fast detect islanding necessity in power systems. The PSO algorithm is used in ANFIS training to determine the optimum membership function parameters and improve the speed and accuracy of islanding detection necessity. The proper inter-area-based extensive area signals are chosen and extensive stability studies are performed to create a proper training database.

After disturbance detection by the proposed method, the wide-area input signals are monitored by an algorithm and in the case of possible asynchronous oscillations, investigating the stability between areas in real-time is initiated by the P-ANFIS algorithm. As the oscillations are detected to be unstable, the islanding command is sent to split related areas from each other to construct stable islands.

The proposed technique is employed for New England 39-bus and demonstrated with the ANN method indicating that the islanding necessity and the time of islanding execution are determined with high accuracy and speed in all disturbances.

APPENDIX

TABLE I

The time of islanding detection by P-ANFIS method and actual angle separation

Areas	Time of detection by P-ANFIS (s)	Time of angle separation (s)
1 vs 2	1.43	1.81
1 vs 6	0.66	1.04
2 vs 7	1.43	1.84
3vs 4	1.43	1.81

TABLE II

The outputs of some ANFISs optimized with PSO in New England 39-bus network at case1

P-ANFIS-PSO method				ANN method [9]			
ANFIS No.	Allocated Areas	Output	Time of detection (s)	ANN No.	Assigned Areas	Output	Time of detection (s)

1	1 vs 6	0.999	0.75	1	1 vs 6	0.998	0.79
2	1 vs 2	0.989	0.72	2	1 vs 2	0.986	0.77
3	7 vs 8	0.015	stable	3	7 vs 8	0.032	stable
4	2 vs 8	0.999	1.48	4	2 vs 8	0.998	1.495
5	3vs 4	0.998	1.42	5	3vs 4	0.999	1.435
7	2 vs 3	0.012	stable	7	2 vs 3	0.0048	stable
8	2 vs 6	0.999	1.43	8	2 vs 6	0.997	1.444
10	3 vs 5	0.996	1.46	10	3 vs 5	0.997	1.471
11	8 vs 4	0.021	stable	11	8 vs 4	0.032	stable
12	4 vs 5	0.032	stable	12	4 vs 5	0.037	stable

TABLE III

The outputs of some ANFISs optimized with PSO in New England 39-bus network at case1

P-ANFIS-PSO method				**P-ANFIS method [12]**			
ANFIS No.	Allocated Areas	Output	Time of detection (s)	ANFIS No.	Assigned Areas	Output	Time of detection (s)
1	1 vs 6	0.999	0.75	1	1 vs 6	0.997	0.77
2	1 vs 2	0.989	0.72	2	1 vs 2	0.984	0.75
3	7 vs 8	0.015	stable	3	7 vs 8	0.024	stable
4	2 vs 8	0.999	1.48	4	2 vs 8	0.967	1.612
5	3vs 4	0.998	1.42	5	3vs 4	0.989	1.402
7	2 vs 3	0.012	stable	7	2 vs 3	0.012	stable
8	2 vs 6	0.999	1.43	8	2 vs 6	0.965	1.487
10	3 vs 5	0.996	1.46	10	3 vs 5	0.999	1.468
11	8 vs 4	0.021	stable	11	8 vs 4	0.036	stable
12	4 vs 5	0.032	stable	12	4 vs 5	0.042	stable

TABLE IV

The outputs of some ANFISs optimized with PSO in New England 39-bus network at case2

P-ANFIS method				**ANN method [9]**			
ANFIS No.	Allocated Areas	Output	Time of detection (s)	ANFIS No.	Assigned Areas	Output	Time of detection (s)
1	1 vs 6	0.998	0.546	1	1 vs 6	0.998	0.576
2	1 vs 2	0.999	0.54	2	1 vs 2	0.999	0.565
3	7 vs 8	0.998	stable	3	7 vs 8	0.998	stable
5	3vs 4	0.997	1.42	5	3vs 4	0.997	1.47
7	2 vs 3	0.017	stable	7	2 vs 3	0.017	stable
8	2 vs 6	0.988	stable	8	2 vs 6	0.988	stable
9	4 vs 6	0.996	1.52	9	4 vs 6	0.996	1.59
10	3 vs 5	0.998	1.44	10	3 vs 5	0.998	1.52
11	8 vs 4	0.997	1.47	11	8 vs 4	0.997	1.54
12	4 vs 5	0.043	stable	12	4 vs 5	0.043	stable

TABLE V

The outputs of some ANFISs optimized with PSO in New England 39-bus network at case2

P-ANFIS-PSO method				**P-ANFIS method [12]**			
ANFIS No.	Allocated Areas	Output	Time of detection (s)	ANFIS No.	Assigned Areas	Output	Time of detection (s)
1	1 vs 6	0.998	0.546	1	1 vs 6	0.998	0.582
2	1 vs 2	0.999	0.54	2	1 vs 2	0.999	0.556
3	7 vs 8	0.998	stable	3	7 vs 8	0.998	stable
5	3vs 4	0.997	1.42	5	3vs 4	0.997	1.52
7	2 vs 3	0.017	stable	7	2 vs 3	0.017	stable
8	2 vs 6	0.988	stable	8	2 vs 6	0.988	stable
9	4 vs 6	0.996	1.52	9	4 vs 6	0.996	1.55
10	3 vs 5	0.998	1.44	10	3 vs 5	0.998	1.57
11	8 vs 4	0.997	1.47	11	8 vs 4	0.997	1.62
12	4 vs 5	0.043	stable	12	4 vs 5	0.043	stable

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