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Distribution Network Reconfiguration Considering Energy Storage Devices Based on Binary Particle Swarm Optimization

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Abstract

This paper studies a new method for reconfiguration of the distribution network that considers access to energy storage devices. Initially, a new distribution network reconfiguration model is being created that takes into account access to energy storage devices. This model takes as an objective function the minimum of network losses and takes into account the current power and voltage constraints induced by energy storage devices. In reconfiguration schemes, the dual power flow directions are also deliberated. To solve the proposed model, the Binary Particle Swarm Optimization (BPSO) is implemented to get the optimal reconfiguration scheme. Finally, to check the correctness and efficacy of the proposed process, two distribution networks with admission to energy storage systems are being checked (Initial topology of 12-bus system - Optimal topology without considering energy storage - Optimal topology considering energy storage), Then proposed more suitable method for solving the proposed reconfiguration models in this manuscript.

Keywords: Distribution Network, Reconfiguration, Energy Storage Devices, Binary Particle Swarm Optimization
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1. Introduction

Energy storage technology has been gradually applied to power systems in recent years. Storage system applications have introduced significant improvements to traditional power planning and service work [1]. Currently, energy storage technology is primarily used in the area ofilizing new energy generation, enhancing the efficiency of power users and rapidly managing power frequency systems[2].

Energy storage unit admission makes the operating mode of the distribution network very different from the preceding. The topology of the delivery network is altered from a single source radiating network to a looping multi-source network. Even, to be bidirectional, the power flow in the line varies. The planning and operating system of the distribution network should also be changed to respond to the admission to energy storage devices. Reconfiguration of the distribution network is a very essential way for power managers to modify power between lines and substations to infer network failure or overloading of the release line[3]-[4]. Energy storage unit access also brings great improvements to the issue of reconfiguration of the distribution network[5].

Centred on the above discussion, this paper discusses the methods of reconfiguration of distribution networks considering admission to energy storage systems. First, a new distribution network reconfiguration model considering access to energy storage devices is installed in this paper. Second, in order to solve the current mathematical model, an improved genetic algorithm is suggested. Finally, two traditional distribution networks with connections to energy storage equipment check the correctness and cogency of the proposed reconfiguration process.

2. Traditional distribution network reconfiguration model

The conventional mathematical model of distribution network reconfiguration is defined by (1)- (6).

$$Min\ v = \sum_{i=1}^{n}\sum_{j=1}^{n} r_{ij}\frac{|S_{ij}|^2}{v_i^2} \quad (1)$$

$$V_{i,min} \le V_i \le V_{i,max} \quad (2)$$

$$|S_{ij}| \le S_{ij\,max} \quad (3)$$

$$\sum_{i=1}^{n} S_{ij} = Sd_j \quad (4)$$

$$g_k \in G_k \quad (5)$$

$$V_i - V_j = Z_{ij}i_{ij} \quad (6)$$

Where n is the number of electrical nodes in the system, and S_{ij} , i_{ij}, and Z_{ij} are the apparent power flow, electrical current and impedance of the branch ij , respectively. g_k is the current radial configuration and G_k is the set of all feasible radial configurations. Sd_j is the load at bus j , V_i is the voltage at bus i [6]-[7].

3. Distribution network reconfiguration considering energy storage devices

Any constraints of the standard reconfiguration model should be updated when considering the admission of energy storage systems in the distribution network. In order to measure the network state with access to energy storage devices, the conventional distribution network power flow algorithm should also be enhanced.

A) New constraints

When accessing energy storage modules, the configuration of the distribution network is modified from a single source network to a multi-source network. The power produced by energy storage devices should therefore be included in the constraints of (2)-(6). In particular, (4) constraints should be changed to (7) and (8) constraints should be added.

$$v_k = V_k \quad K = 1, 2, \dots, n_g \quad (7)$$

$$\sum_{i=1}^{n} S_{ij} = Sd_j + Se_j \quad (8)$$

Constraint (7) refers to the node voltage of the energy storage unit. The voltage is called unvaried for the nodes with energy storage devices and their values are assigned as V_k . The n_g is the number of storage devices for electricity. Constraint (8) is the first law of Kirchhoff that takes into account the generation of energy storage devices, where Se_j reflects the apparent energy flow injected by the energy storage devices in node j.

B) Distribution network power flow considering energy storage devices

To check the protection of the reconfiguration system, distribution network power flow should be measured. The energy storage system nodes in the power flow algorithm are viewed as PV nodes, unlike the load nodes. However, when using conventional forward and backward power flow algorithms, the PV node sort is very difficult to manage with. So, during the measurement process, the nodes of the energy storage devices are specially handled. Sufficient reactive power support should be ready in such nodes in order to make the voltage amplitude in the PV nodes unchanged [8]-[9]. Through the backward and forward power flow estimation method, the equivalent reactive power Q in the PV nodes can be computed and revised. Then, in the energy storage PV node, the reviewed Q and the known P can be joint as a PQ node in the power flow model. During the iteration process, the value of Q should be changed until the measurement converges and the voltages in the energy storage system nodes are equivalent to the values that are known.

The power flow measurement processes that consider energy storage devices are described as follows:

- If the energy storage node is 0, the initial reactive power Q0 in is 0, the reactive power P is the assigned amount and the iteration time is 0.
- Solve the distribution of power in the network by a backward process when Q=Qi in the iteration of the power flow system [10].
- Solve the distribution of voltage in the network in the ith iteration of the power flow process by forward procedure.
- Update the Qi in reactive power of the nodes with power storage devices according to the sensitivity factor index [11].
- If all joining situations are pleased and the voltages in the nodes with energy storage devices are equal to the amounts that are assigned, stop and output the results. Otherwise, i=i+1, go to step 2).

It can be seen from the above solving procedure that the PV nodes are identical to PQ nodes with energy storage units. Such equivalent disposal can prevent the conventional algorithm for forward and backward power flow from being updated. The node voltage and line power in a system with energy storage devices can be measured using the proposed power flow measurement algorithm, and the protection of candidate reconfiguration schemes can be validated.

4. Binary particle swarm optimization

This unit examines the fundamentals of Binary Particle Swarm Optimization and then formulates an intelligent BPSO-based search technique and finds all practicable distribution system configurations that fulfill the objective function. The algorithm preserves a subdivision population, each preserving a distinctive answer. The subdivisions are connected to a randomized speed and are flown through the space of the multi-dimensional search. The initialized subdivision population with random position X_i, velocity V_i and objective function F_i are appraised as input parameters using positional synchronizes and population dimension. Every subdivision keeps track of its location and is called Pbest, which is the best value achieved so far. At the same time, Gbest is stored as the overall best value obtained by any subdivision so far.

The weight of inertia dynamically affects the effect of the previous velocity on the subdivision's current velocity. Experimentally, the decreasing assessment of inertia weight lengthways the iterations is shown to trigger linear exploration and exploitation.

$$V_{ij}^{t+1} = W * V_{ij}^{t} + C_1 r_{1j}^{t}\left[P_{best} - X_{ij}^{t}\right] + C_2 r_{2j}^{t}\left[G_{best} - X_{ij}^{t}\right] \quad (9)$$

where,

v_{ij}^{t} is the subdivision's speed

x_{ij}^{t} is the subdivision's situation

C_1 is the rational parameter and C_2 is the community parameter that reflects the weighting of the term of stochastic hastening that pulls each subdivision respectively to Pbest and Gbest.

r_1 and r_2 are the accidental values that ranges from 0 to 1.

$$x_{ij}^{t+1} = \begin{cases} 1, & if\ u_{ij}^{t} < s_{ij}^{t} \\ 0, & if\ u_{ij}^{t} \geq s_{ij}^{t} \end{cases} \quad (10)$$

Where

u_{ij}^{t} is the random number selected from a identical distribution in (0,1), and

s_{ij}^{t} is the sigmoid function denoted by,

$$s_{ij}^{t} = \frac{1}{1 + e^{-V_{ij}^{t+1}}} \quad (11)$$

This function transforms values from incessant to separate. The overhead function differs, so that the values are selected from the set of switches provided by the bus system. The following are the basic sampling steps:

- Initialize the population, location, random velocities, iterations of Pbest, Gbest and Limit, and the matrix from which the values of the switch are chosen.
- The weight of inertia is determined, the velocity is updated and the positions of the subdivisions are updated.
- Radiality limit is verified, followed by the Pbest's fitness feature calculation. If the estimated fitness function is lower than the previous best value, Pbest is modified.
- Similarly, Gbest's fitness feature is evaluated and it is modified if the value is less than that of the previous version.
- If the maximum iterations are reached or if no new better shapes are found, the search algorithm is terminated.
- Change the speed of the subdivisions using the preceding speed, the distance to Pbest and the distance to Gbest in equation 11, if the conditions are not met.
- The location of the subdivisions from the supplied switches is changed. The algorithm is performed from step 3 by this new position regular and speed. Fig.1 displays the suggested Binary Particle Swarm Optimization flowchart for reconfiguration.

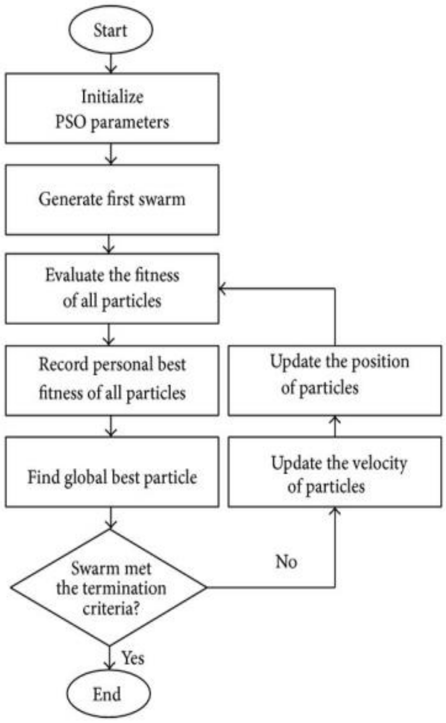

Fig. 1. Basic flowchart of BPSO

5. Test and results

You will find 14-bus device data at [11] and a value of min 0.95 V = p.u. It is used for exams. The data for the load is described in Table 1.

Table.1.
Load data of 12-bus system

Node	*active power (MW)*	*reactive power (MWAR)*
1	0	0
2	2.2	1.7
3	2.5	0.6
4	2.1	-0.5
5	1.6	1.3
6	3.8	2.4
7	4	1.5
8	1.5	1
9	1	-0.4
10	5	-1.5
11	1.2	0.8
12	1	-0.7

Fig.2 shows the initial distribution topology. The solid line represents the segment line and the interconnection line represents the dotted line. With this topology, all protection constraints are met. The initial topology's entire active power loss is 498.2 KW.

The optimal reconfiguration scheme is demonstrated in Fig.3 using the conventional distribution network reconfiguration approach without considering energy storage access. It is possible to satisfy all safety limitations. With this optimal topology, the entire active power loss is 453.5 KW.

Now, suppose that in node 5 and node 11, two energy storage (ES) devices are installed. In Fig.2

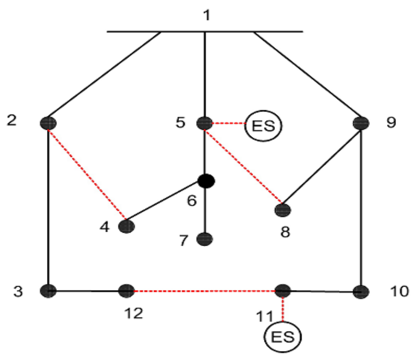

Fig. 2. Initial topology of 12-bus system

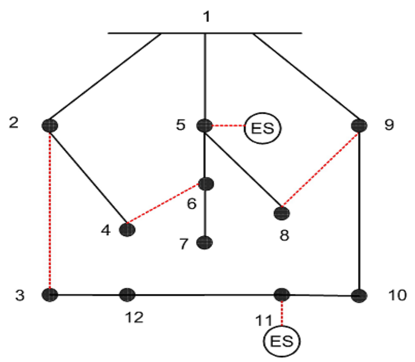

Fig. 3. Optimal topology without considering energy storage

and Fig.3, these two energy storage systems are shown with the mark ES. These two nodes are known to be PV nodes with 4MW active power and 1.0 p.u. voltage. The active power losses are 352.4KW and 311.2KW using the proposed distribution network power flow approach considering access to energy storage devices. From the measurement results, it can be shown that after the access of energy storage devices, the active power loss decreases distinctly. The explanation is that the energy storage systems will supply certain loads locally. When the energy storage devices are mounted, the power transferred from the balance bus to the load bus decreases.

The optimal reconfiguration scheme solved is illustrated in Fig.4, using the BPSO. 321.7KW is the entire active power loss of this optimum topology. It can be seen from the measurement results that the access of energy storage devices affects the distribution of power flow in the network. The ideal reconfiguration method would be very different and the active power loss in the system can be minimized. Table 2 shows the comparison of measurement outcomes for different topologies.

In addition, the proposed BPSO converges to optimal solution in very fast speed compared with genetic algorithm (GA). The conventional GA, however, needs more than 5 iterations to solve the case. The special codification method of BPSO leads to the great improvement in calculation speed. All BPSO generated schemes will automatically satisfy the radial restrictions. The search zone region is thus reduced and radial characteristic validation can be omitted.

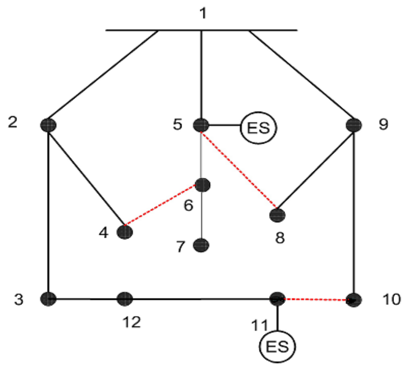

Fig. 4. Optimal topology considering energy storage

Table.2.
Comparison of calculation results

	Interconnection Switches	*Active power loss(KW)*
Initial topology Without ES	2-4 , 5-8 , 11-12	498.2
Optimal topology Without ES	2-3 , 4-6 , 8-9	453.5
Optimal topology With ES	4-6 , 5-8 , 10-11	321.7

The BPSO is often used to address the problem of reconfiguring a delivery network on a wide scale. 33 buses, 37 branches and 4 energy storage systems are integrated into a real distribution system. Table.3 lists the calculation results for optimum reconfiguration schemes. Also highlighted are the comparative findings between BPSO and GA.

It can be shown from Table 3 that the enhanced BPSO is better than the GA when solving large-scale systems in terms of both active power loss and calculation speed. The power flow calculation results are listed in table 4 and table 5.

Table.3.
Comparison of calculation results in real 33-bus system

	Active power loss (MW)	**Calculation Time (s)**
GA	0.92	9.67
BPSO	0.78	4.21

Table.4.
Node voltage of power flow calculation

Node	*Voltage (p.u)*	*Angle*
1	1	0
2	0.991	-0.412
3	0.988	-0.384
4	0.990	-0.632
5	0.996	-0.218
6	0.994	-0.745
7	0.998	-0.891
8	0.992	-1.121
9	0.995	-0.437
10	0.993	-1.521
11	0.997	-0.876
12	0.996	-0.754

Table.5.
Line flow of power flow calculation

Line	*Start Node*	*End Node*	*Active Power*	*Reactive Power*
1	1	2	0.0654	0.0116
2	2	3	0.0281	-0.0009
3	2	4	0.0071	-0.0038
4	1	5	0.0212	-0.0041
5	5	6	0.0862	-0.0498
6	6	7	0.0542	-0.0753
7	1	9	0.0478	-0.0178
8	9	8	0.0412	0.0008
9	9	10	0.0198	-0.0021
10	11	12	0.0098	0.0086
11	12	3	0.0055	-0.0057

6. Conclusion

This paper introduces a new reconfiguration model for the distribution network that considers access to energy storage devices. The generation output and voltage sustaining impact of power storage devices are included in the new model. The power flow system for the distribution network considering access to energy storage devices is proposed. It is used in the suggested BPSO to solve the new model. The proposed BPSO adopts a special method of codification to preserve the radial function in the entire PSO algorithm. In the BPSO, the combination and mutation procedures are also changed to improve the speed of convergence. Tests on two separate systems suggest that access to energy storage devices will substantially reduce the active loss of electricity. The BPSO proposed is more suitable than the GA for solving the proposed reconfiguration model.

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