An Intelligent Approach for Management of Hybrid DG System

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Abstract**—**Distributed generation units (DGs) are grid-connected or stand-alone electric generation units located within the electric distribution system at or near the end user. It is generally accepted that centralized electric power plants will remain the major source of the electric power supply for the near future. DGs, however, can complement central power by providing incremental capacity to the utility grid or to an end user. This paper presents an efficient power dispatching model for hybrid wind-Solar power generation system, to satisfy some essential requirements, such as dispersed electric power demand, electric power quality and reducing generation cost and so on. In this paper, presented some elements of the main parts in the hybrid system; and then made fundamental dispatching strategies according to different situations; then pointed out four improving measures to improve genetic algorithm, such as: modify the producing way of selection probability, improve the way of crossover, protect excellent chromosomes, and change mutation range and so on. Finally, propose a technique for solving the unit's commitment for dispatching problem based on an improved genetic algorithm.

Keywords**—**Power Quality, Wind-Solar System, Genetic Algorithm, Hybrid System.

I. Introduction

RECENTLY the increased interest in the problem of global warming due to the use of fossil fuels has led to a growing concern in new and renewable energy resources. One of its main hazards of fossil fuels is the destruction of the Eco-system. One way to solve this problem is the use of natural renewable energy resources instead of hydrocarbon fuels. The new and renewable energy sources are non-polluting, continuous, and free in their availability. Therefore the new and renewable energy sources have been attractive for many applications as alternative resources [1].

Among many new and renewable energy sources, the wind generator system is free from the environmental concerns. It is also competitive in cost compared to that of the conventional power from the grid. The photovoltaic system, which is one of the major renewable energy and environmentally safe, is still expensive. The operation and maintenance required for the wind and photovoltaic generation systems is very little when compared with the other generation systems such as diesel generation system [2].

Energy is essential to our society to ensure our quality of life and to underpin all other elements of our economy [3]. The escalation in cost and environmental concerns involving conventional electrical energy sources has increased interest in renewable energy sources.

Many societies across the world in which we live have developed a large appetite for electrical energy. This appetite has been stimulated by the relative ease with which electricity can be generated, distributed, and utilized, and by the great variety of its applications. It is arguable whether the consumption of electricity should be allowed to grow unchecked, but the fact is that there is an ever-increasing demand for this energy form. Clearly, if this demand is to be met, then the world's electricity generating capacity will have to continue to grow. Presently almost all the electricity generation takes place at central power station which utilizes coal, oil, gas, water or fissile nuclear material as the primary fuel source. There are problem facing the further development of generating methods based on any of these conventional fuels. Hydro-power generation is restricted to geographically suitable areas, and reserves of coal, although presently plentiful, are not renewable [4]. The possible hazards of nuclear power have been much publicized, particularly those concerning the storage and military use of nuclear waste material. Nevertheless, to assist in maintaining electrical supply in many of our societies it seems likely that an increasing nuclear power presence, involving breeder and possibly fusion reactors, will be tolerated. To achieve this and also to aid in management of the existing fossil-fuel resources, it is essential that some part and an increasing part, of future electrical energy research and development be concerned with so called nonconventional methods of generation Wind- solar PV and fuel cell power generations are visible options for future power generation. Besides being free, they are free of recurring costs.

II. Model of Wind-Solar Generation System

Wind energy, solar energy in time have strongly complementary to each other, so that the wind power and solar power generation systems makes an excellent complement to each other in terms of resources.

So people found that the distributed wind-solar power generation is economic compare with traditional generation, and flexible in generating ways, and can keep good relationship with the environment. So the joint operation with the grid system can enhance the Grid's economy, and flexibility; At the same time, when the traditional power grid face malfunction, they can operate independently from the big grid for electric clients surrounding [4], so it can make better security, reliability, and can meet the sustainable development.

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A. Wind Power Generation

Wind power generation, mainly through the wind turbine to capture wind energy, and transform wind energy into mechanical energy, and then transform mechanical energy to electricity through generator. The forms of wind power can be divided into off-grid and on-grid types. The main equipment of wind farm is wind turbine unit. The generator connects with the grid through pressure boost. Wind turbine generating unit mainly include wind turbine and electric generator.

Wind Turbine:

Wind-turbine captures the wind energy by its blades, and then transform the wind energy to the mechanical wheel torque that act on the wheel hub [5]. For practical wind turbine, the conversion from wind energy which was captured, to mechanical output power P_m can be expressed as follows:

$$P_m = 0.5\rho AC_p V_w^3 \tag{1}$$

where, ρ is the air density (kg/m^3), A is the fan blade sweep area (m^2), V_w is the head-on wind speed (m/s) which act on the wind turbine, C_p is an efficiency coefficient of wind energy converting to mechanical energy. The wind-turbine's overall design and control strategy is to pursue the maximization of C_p, thus increasing the output power.

Generators:

Nowadays, two wind power generators are mainly adopted for wind power generation, which include synchronous generator, especially asynchronous generator. Asynchronous generator is the ideal equipment of wind power generation because of its advantages. It works with low consumption and high reliability, and it can work without excitation devices and brush, and has simple structure and small size, sturdiness and durability, and need little maintenance, etc [6].

Wind power generation makes obvious environmental benefits for its less waste gas emissions. On the other hand, it also can be used to supply electricity for residents of remote rural, pastoral areas or island.

B. Solar Electric Energy Generation

Solar electric energy generation is using semiconductor materials to convert directly solar energy into electricity based on the principle of photoelectric effect. Before supply the electric power, the current went through a full-bridge inverter, the filter inductor, and transformer. Solar power generation and supply can works with off-grid or on-grid forms, so it can be very flexible and convenient. Solar electrical energy generation do not consume fuel, and with features like flexible-size, non-pollution, safety and reliability, and easy to maintain. Output power of photovoltaic cells is affected by the intensity of sunshine, and the battery junction temperature and other factors, thus its output power expression at any time t is:

$$P_g = \frac{I \cdot A \cdot \eta}{860.4} (W) \tag{2}$$

where, I is the total radiation intensity with unit (W/m^2); A is the area of a single solar cell components with unit (m^2); η is the rated efficiency for battery components' conversion. Assume that there are n components in the array, and it can work normally, then the total array output power is $n \cdot P$.

C. Storage Equipment

Storage equipment works with wind power and solar power generation equipments, mainly to achieve two purposes: 1. Power balancing, helps to improve power quality; 2. Load balancing, that is, using as power storage equipment, charging it as electrical load when the grid's electricity is surplus, and discharging it as electrical source when the grid's electricity is scarce, thus playing an important, twofold role flexibly [7].

D. Evaluate the Electric Power Quality

Because wind energy and solar energy will be affected by climate, environment, time and many other factors which with strong randomness. Therefore, distributed wind-solar power generating system will exist many uncertainties in operation, it introduce some negative impacts besides providing clean energy to the power grid, and bring challenge to the safety, reliability and economical efficiency of the power system. So it is necessary to assess and apply power quality of the distributed wind-solar power generating system. In [8] presents a fuzzy comprehensive evaluation method and the weighted average method, as well as introduces some methods such as the weight of vector analysis to assess the wind farm power quality, in order to improve power quality. This provides a workable solution. This paper will use the results of this method to solve the problem of dispatch plan.

E. Mathematical Model of the Problem

To ensure uninterrupted, adequate, high quality and low-price power to the electrical client is the mission of conventional energy power system, as well as distributed wind-solar power generating system. Taking into account its quality and economization, we describe its objective function as follows:

$$\min z = \min \sum_{t=0}^{T} \sum_{i=1}^{N} (k_1 Q_{it} + k_{2t} P_{it}) \tag{3}$$

where, Q_{it} is a power quality assessment value of the unit i at time t; P_{it} is the output active power of unit i at time t, and $f(P_{it})$ is the corresponding costs. The smaller the target value, the corresponding units will be selected as power supply units for output to the load. In addition, the constraint conditions can be described as follows [9]:

1. Power Balance Constraint

$$\sum_{i=1}^{N} P_{it} - P_{Dt} = 0 \tag{4}$$

where, P_{Dt} is the total load at time t, which including the demand load and line loss.

2. Limit of Generator Power Constraint

$$P_i^{\min} < P_i < P_i^{\max} \tag{5}$$

where, $P_i^{\min}$ and $P_i^{\max}$ is the lower and upper power limit respectively, of the unit i.

3. Storage Battery Runs Constraint

$$\begin{aligned} & I_d \le I_{d\max} \\ & I_c \le I_{c\max} \\ & Q_r \ge Q_{\min} \end{aligned} \tag{6}$$

where, I_d is battery discharging current, $I_{d\max}$ is the permitted maximum discharge current of battery; I_c is battery charge current, $I_{c\max}$ is the permitted maximum battery charge current; Q_r is remaining capacity of the battery, $Q_{\min}$ is the permitted minimum residual capacity of the battery.

III. Distributed Generating Units Dispatching Plan

Output of distributed wind-solar hybrid power generating system is loosely including two cases [10]:

On-grid: When the power grid working at trouble-free situation, surrounding loads of the system can access to power supply from the power grid, the system can contribute all its power to the power grid though it first meet the requirement of its storage battery charging.

Off-grid: When the power grid is facing trouble and cannot supply its power, the system is in "isolated island" status, meanwhile the load around the system unable to obtain supply from the big power grid power. The system can supply electricity to the nearest surrounding clients.

This article intends to obtain the scheduling strategies and algorithms mainly based on off-grid situations. Here we consider some conditions:

1). It costs low in operation and maintenance for solar power generation, but will be affected by the time, while sunlight in the daytime is enough, photovoltaic power generation system should be used with prime priority;

2). Wind energy is non-controllable resource likewise solar energy, so when wind resource is sufficient in the evening for power generation, wind power generation also should be used with prime priority;

3). Storage batteries mainly used for dynamic allocation, to absorb the surplus power and complement the power scarcity.

4). Check up the remaining battery power before scheduling each time, if Q_r is less than 20%, and during non-peak period, then recharge it until reach 80%; If Q_r is larger than 90%, then do not charge it.

In addition, in order to ensure safe and stable operation of the grid, and schedule power openly, fairly and justly, we should order the loads according to its significance. Assess characteristics of the region's power grid load, of customer consumption, of the regional economic structure and climate change, of possible electricity supply gap; adopt some measures such as peak averting, peak avoiding, load limiting, resting and shutdown etc. Prepare real-time dispatching plan respectively, and put it into effect. Perform the scheduling solution according to different conditions of power scarcity.

Power system economic dispatch is divided into static and dynamic optimal optimum dispatch. The economic dispatch of distributed wind-solar power generation system mainly adopt dynamic model because of wind speed, sunlight intensity etc. and so on will change randomly, then such a calculation results more in line with actual requirements. In this paper, the improved genetic algorithm is adopted to solve the issues raised.

IV. Solver Problems Using Improved GA

Combination of distributed power sources is a of high-dimensional, non-convex, discrete and non-linear optimization problem, it is difficult to find the optimal solution. In order to obtain a satisfactory solution for applications of unit commitment problem, we try to improve some operation methods based on the Basic Genetic Algorithm. Concrete improvements for Genetic Algorithm are as follows:

A. Modify the Producing Way of Selection Probability

Genetic algorithm is a randomized algorithm, selections of producing new species, chromosome involved in crossover operation, crossover position, mutation position and so on, have adopted random factors. Particularly, roulette selection for new species can be affected significantly by random factors – that may miss some excellent species. In order to reduce the impact on natural selection by pseudo-random number, we introduce weighted coefficient – using the kth power of adapted value as weighted coefficient, then carry out weighted calculations on roulette selection probability, and the last results is selection probability. Its formula can be expressed as,

$$p_{s_k}^{[i]} = \frac{f_i^{k+1}}{\sum_{j=1}^{n} f_j} \Bigg/ \sum_{j=1}^{n} \frac{f_j^{k+1}}{\sum_{l=1}^{n} f_l} \tag{7}$$

where, f_i is the adapted value of the i^{th} chromosome, $p_{s_k}^{[i]}$ is the k^{th} power of weighted calculation result of the ith chromosomes in the population.

B. Improved the Way of Crossover

The crossover operation of basic genetic algorithm, including single-point, two points, or uniform crossover ways and so on, but optimization and search capabilities are not so much strong. Thus we introduce the way of single-point crossover on each variable, just like the definition as follows.

Definition 1. Single-point crossover on each variable: Assumed that the objective function contains m variables, and the variable is encoded with binary code, its length is $l_1, l_2, \cdots, l_m$ respectively. We define the binary code of chromosomes A and B, and crossover process as the following,

$$\begin{aligned}
&A:\ a_1 \ldots a_{k_1} a_{k_1+1} \ldots a_{l_1}, c_2 \ldots c_{k_2} c_{k_2+1} \ldots c_{l_2} \ldots\ldots \\
&B:\ b_1 \ldots b_{k_1} b_{k_1+1} \ldots b_{l_1}, d_1 \ldots d_{k_2} d_{k_2+1} \ldots d_{l_2} \ldots\ldots \\
&\ldots\ldots \\
&\ldots\ldots \\
&A':\ a_1 \ldots a_{k_1} b_{k_1+1} \ldots a_{l_1}, c_1 \ldots c_{k_2} d_{k_2+1} \ldots d_{l_2} \ldots\ldots \\
&B':\ b_1 \ldots b_{k_1} a_{k_1+1} \ldots b_{l_1}, d_1 \ldots d_{k_2} d_{k_2+1} \ldots c_{l_2} \ldots\ldots
\end{aligned} \tag{8}$$

then, with the points of hyper-plane, it can be expressed as,

$$\begin{aligned}
&A(x_1, \cdots, x_m) \xrightarrow{\text{crossover}} A'(x'_1, \cdots, x'_m) \\
&B(y_1, \cdots, y_m) \xrightarrow{\text{crossover}} B'(y'_1, \cdots, y'_m)
\end{aligned} \tag{9}$$

where, $x_k \to x'_k$ and $y_k \to y'_k$, $(k = 1, 2, \cdots, m)$, which has relationship of increase-decrease respectively: If $x'_k = x_k \pm \varepsilon$, then has $y'_k = y_k \mp \varepsilon$, and among them, $\varepsilon = (string_2)_{10} \cdot \frac{2^{(l_k - t_k)} - 1}{2^{l_k} - 1}$, l_k is the encoding length of the k^th^ variable, t_k is crossover position of the corresponding variable through random selected, $string_2$ is the difference of two strings code behind t_k. In the algorithm programming, the change range of t_k is controllable, which can ensure small-scale changes around the original position after the variable was carried out crossover operation. So this way of crossover operation is using for optimization firstly, and search in small-scale secondly.

C. Protect Excellent Chromosomes, Especially Select Better Chromosomes After Crossover Operation

Store the original chromosomes before crossover operation; and compare the crossover result with the backup to bring two better chromosomes into new population. Obviously, this way is more active and more effective than elitist model, the latter force the best chromosome of the old population into the new one, and it may enhance convergence and efficiency of the algorithm.

D. Change Mutation Range, Let Mutation Operation be the Major Means of Search

We note that the basic genetic algorithm, as well as a number of other improvements, their mutation operation is aim at all chromosomes, its advantage is enhancing the searching ability, but on the other hand, it may lead to bad operation – the original best chromosome may lost after a mutation operation on it. To avoid that disadvantage, we divided the population into two parts, one part is for crossover operation, and the other part is only for mutation. Looking back to the above description, crossover operation is beyond mutation operation, and crossover operation to one part had obtained the best chromosome, so mutation to the other part will not affect the excellent chromosomes, but keep the searching ability at the same time. All in all, the above four improve ways and their comprehensive application, crossover mainly obtain optimization which enhance convergent accuracy and crossover mainly for searching which would not trap in partial domain, can complement to each other, and obtain the content solution rapidly.

V. Examples and Analysis

Here we give an example of a simplified operation, the system has 4 wind-driven generation, its capacity, is 20*kW*, 18*kW*, 18*kW*, 16*kW* respectively; and 3 solar generator sets, its capacity is 16*kW*, 15*kW*, 14*kW* respectively; and 1 storage batter set, its inverter power is the 5kW, and its maximum rechargeable power is 10*kW*. It can be named as 1, 2, to 8 set respectively and sequentially. For a certain period of time during daytime, the electricity quality value of each unit was 3.21, 5.66, 4.95, 4.33, 1.27, 0.82, 0.69, and 2.54. The remaining battery capacity is 40%, with a total load of 70*kW*. And at a certain period of evening, the electricity quality value is 3.25, 5.60, 5.00, 4.11, ∞, ∞, ∞ and 2.15 respectively. The total load is 76*kW*.

To solve the problem, we set 100 as population size, crossover probability is 0.4, and mutation probability is 0.2, and evolves 500 generation to the termination. Finally get the results as shown in Table I where the combination of 1, 2, …, 8 unit in sequence from left to right, 1 represent supplying power, and 0 represent stop supply, -1 represent battery charging.

TABLE I
UNITS' COMBINATION AT DIFFERENT TIMES

Time	Total Loads (*kW*)	Target Value z_t	Unit Combination
t_1	70	20.60	$\{0011, 111, -1\}$
t_2	76	27.23	$\{1111, 000, 1\}$

The results can be seen from the above, give the prime priority to the use of solar energy resources as the light intensity is enough in the daytime; give first priority to the use of wind energy resources as wind power is enough at night; to meet loads during daytime, and then recharge the storage batteries if there is surplus power; The batteries need to take the responsibility of supplying power during the evening if occurs power shortage. In case of larger loads and power shortage at the same time, we can take some measures such as avoid power peak, alternate power peak, limit loads, rest by turns, or suspend production etc.

VI. Conclusions

This paper analyzes the characteristics of the main parts of distributed wind-solar power generation hybrid system, and bring forward units combination model. And introduce improved genetic algorithm (improved selection probability, crossover operation and mutation operation), to solve the unit commitment problem which meet requirements of security, economy and high quality. It satisfies the basic requirements of power system.

In addition, due to combination of distributed powers in itself is a complex problem, the actual scheduling process may occur more unpredictable problems, therefore it is necessity for more further research on more realistic and intelligent scheduling strategy to response to a variety of possible situations.

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