Genetic Algorithm Principle and the Application in Oilfield Development

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***Abstract*—The genetic algorithm is a global optimization method and good at flexibility and robustness. It conducts undirected random search, which is not limited by search space. The computational procedure of the algorithm is easy and simple. The genetic algorithm is especially suited to solve multivariate and nonlinear complex problems which are impossible or difficult to be settled by other scientific technologies. The paper introduces the current wide application of genetic algorithm in oil-field development planning, measure optimization, well location deployment, multilateral well design, well testing, steam stimulation, the design of oil production technologies, and so on, which represents the algorithm's advantages in solving problems of oil field development, and reveals the wide ranging application prospect in the field of oilfield development.**

Keywords—Genetic Algorithm; Oil-field Development; Non-linear; Optimization; Application

I. INTRODUCTION

The Genetic Algorithm(GA) is a self-adaptive global optimization probabilistic search algorithm developed through the simulation of living creature's genetic and evolutionary process in natural environments. Originated from the study of natural and artificial self-adaptation systems, the algorithm was proposed by Holland in 1960. It is mainly characterized by the coding operation of parameters. And it doesn't need any relative system's experience or knowledge to carry out parallel search along various routes, and will not fall into the trap of local superior point and can find the global optimization point, thus it is very suitable to tackle multivariate and nonlinear complex problems impossible and difficult to be settled by other scientific technologies [1]. In recent years, the genetic algorithm has been widely applied in many fields in the world, including engineering design, manufacturing, artificial intelligence, computer science, bio-engineering, petroleum exploration, automatic control, social sciences, commerce and finance, etc. Its application in the oilfield development demonstrates the even broader application prospect.

II. THE BASIC PRINCIPLE AND CHARACTERISTICS OF GENETIC ALGORITHM

A. The Principle of GA

GA is a computing model simulating Darwin's evolution of biological species by genetic selection and natural elimination. The idea is originated from biogenetics and the natural law of survival of the fittest, as a result, it is a search algorithm of iteration process combining "survival and test". With all the individuals in a group as subjects, GA utilizes randomized technological guidance to implement high-efficiency search on an encoded parameter space. Selection, crossover and mutation form the genetic manipulation of GA. The five factors of parameter coding, initial population setting, fitness function design, genetic operation design and control parameters setting constitute the core content of GA, and the basic steps are listed below:

1) The creation of initial population: In this step N initial chromosomes(a string of data or array)are randomly generated and formed a population.

2) Adaptability evaluation: In this step it is to build an evaluation function to determine individual's fitness value and assess its quality, which is the basis of genetic manipulation. Generally speaking, the fitness function is converted from objective function.

3) Selection operation: In this step it is to select good chromosomes from current population and make them become the new generation chromosomes, then produce a new population.

4) Crossover operation: In this step it is to conduct crossover operation on the good parent generation, and to choose Pc × N (Pc is the predefined crossover probability value) chromosomes from N chromosomes to conduct the crossover operation.

5) Mutation operation: In this step it is to choose Pm × N (Pm is the predefined mutation probability value) chromosomes from N chromosomes to carry out mutation operation.

The chromosome created after the five steps are called progeny chromosome. By repeating the selection, crossover and mutation operations on the progeny

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chromosomes, and after a given number of times of iterative processing, the best chromosomes will be the optimal solutions of the optimization problem.

B. The Characteristics of GA

1) Self-organization and self-adaptation. When using the GA to solve problems, after deciding the coding scheme, fitness function and genetic operators, the algorithm will utilize the information acquired in the evolutionary process to organize searches by itself. Because the nature-based selection scheme is "survival of the fittest, elimination of the unfitted", individuals with greater fitness have a higher probability of survival, and progeny generations with more adaptability to the environments may appear through genetic operations such as gene recombination and gene mutation. The features of self-organization and self-adaptation make GA simultaneously embody the ability to automatically discover environment traits and laws based on the environment changes.

2) GA conducts evolutionary operations after encoding the problem parameters into "chromosomes", rather than dealing with the parameters per se, which enables GA not to be limited by functional constraint conditions, such as continuity and derivability of functions.

3) GA's searching process starts from a solution set of the problem concerned, rather than from single individuals, and it has characteristic of implicit parallel search, hence considerably reducing the possibility of local minimum.

4) All the genetic operations of GA are random, at the same time, GA bases on individual's fitness value information to carry out searches, with no requirement of other information, such as derivative information.

5) GA is capable of global searching, and best at solving complex and nonlinear problems.

III. GA'S APPLICATION IN OILFIELD DEVELOPMENT

A. GA's Application in Oilfield Development Planning

In recent years, the use of GA to build oil field development planning optimization model begins from two approaches: one of which is, macroscopically, to build a nonlinear planning model of oil field development regarding the overall planning of oilfield [2]. It means to decompose the oil field production, and considers the maximum of the total production revenue as the optimal objective, and puts production cost per ton oil, investment, etc. as constraint conditions, in a move to establish nonlinear optimization model of production composition, then the nonlinear relation between production and workload is calculated by the polynomial least-square curve-fitting, afterwards the annual total output and every regional output as well as cost, profit and other indicators in the planning period are revealed by GA. The other one is to implement a study on the production engineering measure planning in accordance with the actual production case of the oil field [3]. Because the oil field stable production measure planning is featured by multiple variables, multiple constraints, multiple stage optimization, based on the analysis of measure planning influence factors and measure economic profit evaluations, a comprehensive consideration should be taken on the measure effect, water content, cost and other factors then set up a profit maximization nonlinear measure planning model. According to the model characteristics, different chromosome coding forms should be employed to apply GA optimizations such as fracture, acidification, patching holes, pump replacement, water plugging and other oil production process measures.

B. GA's Application in Well Pattern Optimization

Ding Hua, Wang Xiu-kun [4] used GA to study the problem of wellhead orientation of cluster well group. The problem of selecting the optimal point as wellhead is abstracted into the optimization problem of finding the minimal sum of the distances between every vertex and convex polygon in plane. When solving problems with GA, a binary string with the length of 10b should be used to represent respectively two coordinate variables forming genetic code string. The comparison between this method and exhaust algorithm (currently used in engineering practice) shows the method has better astringency, and when the iteration number reduces, the computing speed will be dramatically increased.

Li Xiao-ming et al [5] applied GA to solve such problems as the selection of multiple decision variables and combinatorial optimization during the well deployment. They considered reservoir and fluid characteristics, drive mode and other important factors as well as economic parameters, established the optimization model of well position aimed to obtain the maximal accumulated output and the highest economic profit of oil field, introduced the improved niches genetic algorithm based on share mechanism of fitness values, used the FORTRAN language to program, in order to conduct the optimization of well position and the number of wells for a certain oil field.

C. GA's Application in the Optimization Deployment of Multilateral Wells

Burak Yeten et al [6] used GA combined with artificial neural net, hill climbing algorithm, grid coursing to implement well-type optimization, spatial location optimization, and wellbore trajectory optimization. They fully considered the heel-end and toe-end location, included angle, length, joint points and diameter of multilateral wells and main well holes as well as other influencing factors, and put NPV or maximal accumulated output of the oil field as objective function. They regarded all the designed wells cannot intersect other wells or multilateral well tracts in the oil reservoir grid and in the designed tracks, therefore the

designed track complies with the defined constraint conditions of anisotropic or stress direction. The chromosome encoding uses 5-bit length binary string to represent every parameter, in order to form the entire gene encoding strain of multilateral wells. The model was used in gas cap and bottom water reservoir, stratified deposit reservoir, fluvial facies sedimentation reservoir, concluding that GA is suitable to carry out the optimization deployment of multilateral wells, better than random selection of well type, at the same time, the selection of multilateral well types and oil reservoir type, objective function and undefined factors in oil reservoirs are closely related with each other.

D. GA's Application in the Design of Oil Production Technology

The oil well inflow performance reveals the relationship between well yield and flowing bottom hole pressure, and sufficiently reflects the reservoir's deliverability to oil wells. Site engineering staff built many mathematical models depicting the oil production process to improve the oil-production efficiency, particularly the prediction model of oil well inflow performance. Cuan Jin et al [7] put out an improved BP network model based on genetic variations, and studied a nonlinear synthetic function which represents fluid production rate as such parameters as drainage radius, well hole radius, effective pay thickness, effective formation thickness, FBHP, skin coefficient, water cut and gas-oil ratio, and established prediction model of oil well inflow performance, and utilized the neural network method to predict. Since the BP algorithm easily creates problems such as local extremum, low convergence speed, genetic mutation should be introduced when the BP algorithm's learning process is in the local minimum. Using the mutation operator's features of searching global solutions with a relatively bigger probability in the entire variable space, the global optimization point can be otained by learning with the BP near the solution point.

E. GA's Application in the Optimization of Injection-production Parameters of Steam Stimulation

Using steam stimulation to develop heavy oil reservoir is a complicated system engineering, whose effect is subject to influences of formation parameters, column performance and injection-production parameters. Shi Jun-feng et al [8] based on periodic oil production rate computation, put cyclic annual daily profit maximization as optimization aim, and used the GA as an approach to conduct comprehensive optimization design on steam injection pressure, steam injection dryness, steam injection rate, cyclic steam injection volume and BHFP. Wang Ya-ru et al [9], in deciding the hollow sucker rod steam process technology parameters, considered that the wellbore temperature distribution mathematical model of heat tracing technology has ordinary differential nonlinear equation group with semi-implicit boundary conditions, and that the numerical method takes a long time to solve problems. As a consequence, an optimization objective function was established with the wellbore temperature not fewer than the inflection temperature as constraints, and the function used GA to conduct optimization design on circulating thermal fluid's parameters, which largely reduced the computing time.

F. GA's Application in Well Fracturing

Parameters that influence the fracturing effect include geological static, development dynamic and fracturing construction ones, and every parameter impacts the fracturing effect in different degrees. In choosing high-efficiency fracturing measure well and the research on influencing factors of fracture simulation using fuzzy clustering, fuzzy neural classification system and fuzzy ranking method, Wu Jian-fa [10] proposed an improved self-adaptation genetic algorithm, which let the crossover probability Pc and the mutation probability Pm change automatically with the fitness. Wu also combined the genetic algorithm and neural network, optimized the structure and weights of neural network, and formed the improved genetic neural network. With fast convergence and strong generalization capability, the network overcomes the shortages(limitations and big error) of conventional mathematical methods when dealing with such problems. The application effect shows the predicted results with the method match well with the yield increasing effect after on-site fracturing.

G. GA's Application in Well Test Analysis

In explaining the interference test, Dong Ming et al [11] introduced genetic algorithm, and solved the reservoir parameters regarding the nonlinear relation between line source pressure and reservoir characteristic parameters. Compared with conventional methods, the new method for interference test explanation has characteristics of not demanding the continuity of objective function, not needing initial value prediction, fast computational speed and high accuracy. Due to the characteristics of fractured well test evaluation such as many model parameters and difficulty in explanation, in solving finite-conductivity fractured well explanation model, Duan Yong-gang,Chen Wei et al [12] applied the hybrid genetic algorithm(combined GA and conventional algorithm),which employs floating-point encoding mode and least absolute variance algorithm with stronger robustness as conventional optimization methods, that is to say, GA is used to optimize selection of initial value individuals, the conventional method is employed to search local optimization points, and the

extremal point is used to evaluate individual's fitness value. The application of HGA realizes the fast and reliable automatic fitting in explaining automatic well test.

IV. CONCLUSIONS

Experimental studies indicate that GA is a very practical global optimization genetic algorithm, which represents advantages in dealing with multivariable selection, combination and optimization problem, thus providing a new approach to solve complicated problems encountered in the field of gas and oil field development. However, in actual application, GA has some shortages, for example, sometimes it is easy to find premature convergence and weak convergence ability in practical application. Therefore, studies must be strengthened on the effective combination of high convergence speed, genetic operators and neural network, fuzzy theory as well as chaos theory. In the practice of oil and gas field development, the application of GA is at the starting stage, and it requires further expansion and deepening. As the application range widens, through continuous exploration and improvement, GA will be further developed and ameliorated, and its application prospect will be wider and wider.

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