Voltage Source Converter In HVDC Transmission with Optimization of Its Performance Parameters Using Genetic Algorithm

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Abstract
The strategy of control for high-voltage direct current system on voltage-source converter VSC-HVDC is based on an important element which is PI controller. Because of its simple structure and strong robustness in a wide range of serving conditions, it has been used in the control system in the last few years. Therefore, it is important for the VSC-HVDC system permanent regime to choose proper PI parameters. The use of conventional techniques to find suitable PI parameters creates a number of challenges for the system operators, because it is a difficult process and time consuming. In this paper, a new GA intelligence algorithm called optimization is introduced to find the optimal parameters of the PI controller. This approach offers great flexibility for the permanent regime recovery and improves the stability of the VSC-HVDC link compared to conventional techniques. The obtained results are presented to show the effectiveness of the proposed GA implementation for optimal controller design for VSC-HVDC transmission. MATLAB/Similink simulations are provided to demonstrate the performance of the proposed approach.

Keywords: VSC-HVDC · GA approach · Optimization · PI controller · algorithms · Parameters · Performance

I. INTRODUCTION

Voltage Source Converter High Voltage Direct Current (VSC-HVDC) transmission systems, as a part of electrical power grids, have complex and nonlinear natures which may either/both negatively influence the system's stability and its performance or/and restrict the transmission line capacity [1]. Such complex nonlinear electrical networks present great challenges because of the uncertain parameters, unmodeled dynamics, and unknown disturbances. The power transmission problem has become one of the key issues for restricting the development of offshore/isolated-onshore wind farms using VSC-HVDC technologies for long-distance transmission and guaranteeing adequate system dynamic performance and network power quality [2].

II. APPLICATION OF FACTS DEVICES TO POWER SYSTEM

With the development in the modern power system, it becomes very important to control the power flow along the transmission corridor. Very long high power transmission lines have high series reactance and shunt capacitance. It becomes more difficult to control voltage, power and stability by conventional means. The desire is to find a solution to these problems and limitation led to focus technological developments under FACT (Flexible AC transmission) system. The FACTS technology is not a high power controller, but rather a collection of controllers, which can be applied individually or in coordination with others to control one or more interrelated system parameters mentioned above. A well-chosen FACTS controller can overcome the specific limitations of a designated transmission line or corridor. Because all FACTS controllers represent applications of the same basic technology, their production can eventually take advantage of technologies of scale. Just as the transistor is the basic element for a whole variety of microelectronic chips and circuits, the thyristor or high power transistor is the basic element for a variety of high power electronic controllers. Use of Flexible AC Transmission systems controllers in a power system has the following benefits [3].

- Control the power flow in a transmission line
- Increase the load capability of lines
- Limits the short circuit currents and overloads, prevents blackouts, damp power system oscillations, mitigate sub synchronous resonance, and alleviate voltage instability.
- Reduce reactive power flow.
- Prevents loop power flow.
- Decrease overall generation reserve requirement of interconnected areas.
- Improve HVDC converter terminal performance.
- Wind power generation system.

III. POWER SYSTEM STABILITY

Power system stability has been recognized as an important problem for secure system operation since the 1920s. Many major blackouts caused by power system instability have illustrated the importance of this phenomenon. Historically, transient instability has been the dominant stability problem on most systems and has been the focus of much of the industry's attention concerning system stability. As power systems have evolved through continuing growth in interconnections, use of new technologies and controls, and the increased operation in highly stressed conditions, different forms of system instability have emerged. For example, voltage stability, frequency stability and interred oscillations have become greater concerns than in the past. This has created a need to review the definition and classification of power system stability. A clear understanding of different types of instability and how they are interrelated is essential for the satisfactory design and operation of power systems. As well, consistent use of terminology is required for developing system design and operating criteria, standard analytical tools, and study procedures. According to the IEEE standards, power system stability is defined as: "Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact". A typical modern power system is a high-order multivariable process whose dynamic response is influenced by a wide array of devices with different characteristics and response rates. Stability is a condition of equilibrium between opposing forces. Depending on the network topology, system operating condition and the form of disturbance, different sets of opposing forces may experience sustained imbalance leading to different forms of instability. In this section, a systematic basis for classification of power system stability is provided. The classification of power system stability proposed here is based on the following considerations [4]:

- The physical nature of the resulting mode of instability as indicated by the main system variable in which instability can be observed.
- The size of the disturbance considered which influences the method of calculation and prediction of stability.
- The devices process, and the time span that must be taken into consideration in order to assess stability.

IV. APPLICATION OF SOFT-COMPUTING TECHNIQUES

In conventional mathematical optimization techniques, problem formulation must satisfy mathematical restrictions with advanced computer algorithm requirement, and may suffer from numerical problems. Further, in a complex system consisting of a number of controllers, the optimization of several controller parameters using the conventional optimization is a very complicated process and sometimes gets stuck at local minima resulting in sub-optimal controller parameters. In recent years, one of the most promising research fields has been "Heuristics from Nature", an area utilizing analogies with nature or social

systems. Application of these heuristic optimization methods
a) may find a global optimum,
b) can produce a number of alternative solutions,
c) no mathematical restrictions on the problem formulation,
d) relatively easy to implement and
e) numerically robust.
Several modern heuristic tools have evolved in the last two decades that facilitates solving optimization problems that were previously difficult or impossible to solve. These tools include Evolutionary Computation, Simulated Annealing [4, 3], Tabu Search, Genetic Algorithm [2, 5], Particle Swarm Optimization [6, 7], Gravitational Search Algorithm [7, 2] etc. Among these heuristic techniques, Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Gravitational search Algorithm (GSA) and hybrid optimization techniques appeared as promising algorithms for handling the optimization problems. These techniques are finding popularity within the research community as design tools and problem solvers because of their versatility and ability to optimize in complex multimodal search spaces applied to non-differentiable cost functions. A brief description highlighting the salient features and characteristics of some of the conventional algorithms is presented here which are used for our future studies.

V. RESEARCH MOTIVATION

In the past five decades, significant development of the high voltage direct current (HVDC) has occurred. It has to be a reliable and valuable transmission field for electrical energy. Most of these transmission systems have used the line commutated converter (LCC) that is based on current-source converter (CSC) using thyristor technology. The limitations of this technology reside in the control of the thyristor that cannot be turned off directly with gate signal [1]. With the development of power electronics technology, Voltage-source converter-based HVDC (VSC-HVDC) transmission technology developed rapidly. Compared with the AC connection and classical HVDC connection, VSCHVDC has the following advantages [2]: VSC-HVDC not only can control the active power and reactive power independently, but also supply power directly to the weak power system and passive network; VSC can play the role of reactive power compensator, compensate AC bus reactive power dynamically and stabilize the AC bus voltage. VSC-HVDC can improve system voltage stability. It is not subject to transmission distance and transmission capacity. It can be used for grid-connection of large off-shore wind farm [2]. So VSCHVDC has been, and is becoming a more effective, solution for long-distance power transmission especially for off-shore wind plants and supplying power to remote regions [3]. It is possible that VSC-HVDC will be one of the most important components of power systems in the future. The operating characteristics of VSC-HVDC are directly determined by controllers and system parameters. For grid-connected VSCs, a hierarchical control structure with inner loop current controllers and outer loop controllers are often adopted. The outer loop controllers produce reference values for the faster acting inner loop current controllers. Typically, the sending end converter controls the real power and the receiving-end converter regulates the DC voltage. The reactive power at either end of the link is controlled separately by the respective converters [3].
Control system and control strategy have notable effect on the characteristics of the VSC-HVDC system. A good control strategy depends on a precise mathematic model. The VSCHVDC operating characteristics can be controlled through a closed loop composed of control units and the system. PI (i.e. proportional plus integration) controller, with its simple structure and strong robustness in a wide range of serving conditions, has been

widely used in industry control. Therefore, it is important for the steady operation of VSC-HVDC system to choose proper PI parameters [4]. Authors in [5–7] choose the control system of the VSC-HVDC using an inner control loop and outer control loop in rectifier and inverter side. They use different ways to find suitable PI controller parameters. The selection of suitable PI parameters creates problems for network operators because the designing of optimal parameters for the PI controllers is a difficult calculating and time consuming. Authors in [8] use PSO approach to improve the VSC-HVDC link stability but even it presents good convergence speed, results are got with low precision. To contribute in solving this problem, our paper presents a new bacterial foraging optimization algorithm (BFOA). The BFO approach presents the advantage of high accuracy to obtain proper PI parameters. This approach has been applied to the outer control loop and inner current control loop, on either VSC-HVDC side. The work compares results of classical techniques and those obtained using this approach. Some results illustrating the validity of the proposed BFO algorithm are presented to be in good agreement.

VI. SYSTEM TOPOLOGY

The basic structure of the VSC-based HVDC link, consists of two converters, two transformers, DC-link capacitors, passive high-pass filters, phase reactors and DC cable. The VSCs

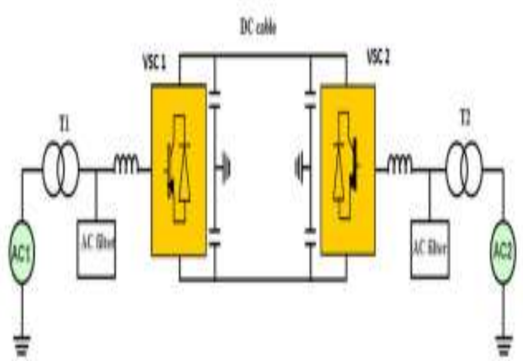

Fig. 1 The configuration of VSC-HVDC transmission

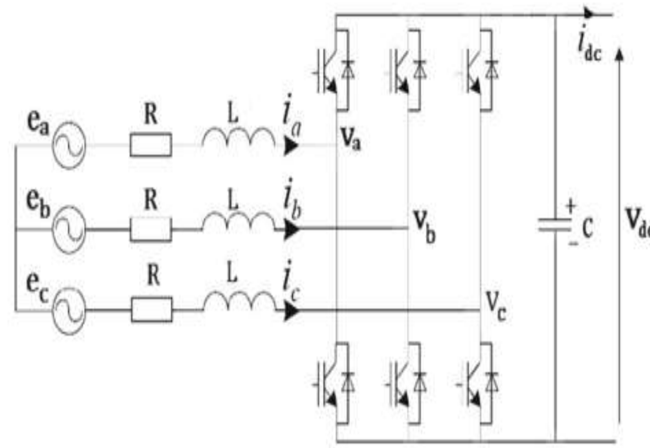

Fig. 2 Basic structure of VSC-HVDC converter as shown in
Fig. 1 are composed of six-pulse bridge equipped with self-commutating switches (IGBTS) and diodes connected in anti-parallel. The DC voltage is maintained constant and the complexity of control is increased compared to classical HVDC system. The two VSCs may be seen as the core of this transmission system topology. One of the VSCs works as rectifier, while the other one works as an inverter.

VII. OPTIMIZATION FRAMEWORK

This section describes the components of the simulation framework that seamlessly integrates simulation tools from different vendors in addition to the developed tools. This way, the individual parts or components no longer need to be designed apart from each other. Furthermore, integrated simulation facilitates developing the design and test of the optimization problem and system. It can be used also for parameter optimization of the different components of the system. With simulation, real reference experiments can be later conducted to enhance the verification of the virtual models using real reference experiments. The framework can accomplish detailed analysis of precise system behaviors. A typical construction and operation of the framework is shown in Fig. 4. The detailed algorithm of GA is presented next by first defining the fitness function f(x). In the

VSCHVDC, it is requested to optimize eight controller parameters (four gains for each side or a couple of gains for each control signal). The GA problem dimensions are set to eight. The population size is fixed to 100 which is sufficient for this problem with a large number of variables to prevent failures due to bias by the highest fitness individuals as suggested by Liepins and Hilliard [4]. To speed up the optimization process, all the initial population is set, which was obtained with the final tuning of the CSMC controller. After some preliminary tests, the value is attained for the desired number of generations. This value is a good compromise between the overall simulation time and the obtained performance. The stall generations limit is set to 1 that force finishing the optimization process for no change in the best fitness value. With the aforementioned options, the GA optimization is run on the model. The optimization process terminated due to stall generation limit as shown in Fig. 4(d) GA curve which plots the percentage of stopping criteria satisfied. The fitness value did not improve any further after generation as shown in Fig. 4(a) dc link voltage where the best and mean score of the population at every generation are demonstrated. The range (the minimum, maximum, and mean) of fitness function values in each generation is depicted in Fig. 4(c) reactive power from which the best fitness value for a population is the smallest fitness value for any individual in the population. Fig. 4(b) active power illustrates the average distance between individuals at each generation. the plot indicates that individuals have a reasonable high diversity due to the large average distance till generation which enables the algorithm to search a larger region of the problem space. The individuals for the controller parameters giving the best fitness value are provided to the system model to further investigate the system performance with them.

VIII. PROPOSED ALGORITHM GENETIC ALGORITHM (GA)

The GA is basically a search algorithm in which the laws of genetics and the law of natural selection are applied. For the solution of any optimization problem (using GA), an initial population is evaluated which comprises a group of chromosomes. Initially, a random population is generated, then from this population fitness value of each chromosome is calculated. This can be found out by calculating the objective function by the process of encoding. Then a set of chromosomes termed as parents are evaluated which are known as offspring generation, which are generated from the initial population. The current population is replaced by their updated offspring that can be obtained by considering some replacement strategy. Fig. (3) shows the flow chart for the Genetic algorithm [12].

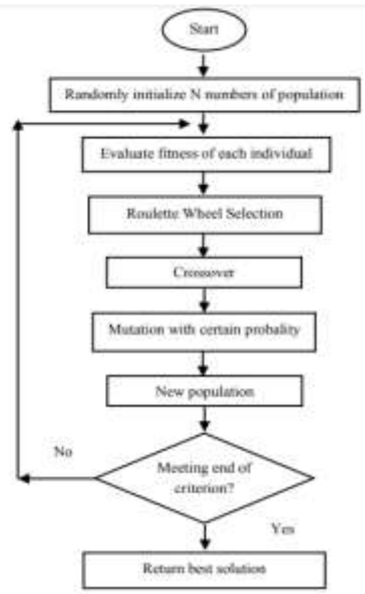

Fig. 3: Flow chart for Genetic **Algorithm**

The genetic algorithm begins with a set of solutions (represented by chromosomes) called the population. Solutions from one population are taken and used to form a new population. This is motivated by the possibility that the new population will be better than the old one. Solutions are selected according to their fitness to form new solutions (offspring); more suitable they are, more chances they have to reproduce. This is repeated until some condition (e.g. number of populations or improvement of the best solution) is satisfied. The basic steps for the algorithms can be stated as [6]:

- Step-1: Generate random population of n chromosomes (i.e. suitable solutions for the problem).
- Step-2: Evaluate the fitness f(x) of each chromosome x in the population.
- Step-3: Create a new population by repeating following steps until the new population is complete.

I. Select two parent chromosomes from a population according to their fitness (better the fitness, bigger the chance to be selected)

II. With a crossover probability, cross over the parents to form new offspring (children). If no crossover was performed, the offspring is the exact copy of parents.

III. With a mutation probability, mutate new offspring at each locus (position in the chromosome).

IV. Place new offspring in the new population.

- Step-4: Use newly generated population for a further run of the algorithm.
- Step-5: If the end condition is satisfied, stop, and return the best solution in the current population.
- Step-6: [Loop] Go to step 2 The genetic algorithm's performance is largely influenced by two operators called crossover and mutation. These two operators are the most important parts of GA.

IX. RESULT AND SIMULATION

Low-frequency oscillation seems to be a major problem associated with an interconnected power system having by a weak tie-line. If the damping of the system is not adequate, then it leads to system separation. In fact, such a situation occurs during a change in the loading condition of the transmission line [10]. Recently Flexible A.C. transmission system (FACTS) based controller is used in the power system to enhance the system stability [70]. The VSC is a primary member of the FACTS family which is used to improve the system damping. The key feature of the VSC is that it can modulate its reactance such that the effective value can span from capacitive to inductive [5]. In order to improve the system stability, an auxiliary stabilizing signal is used in the control function of VSC [7]. The application of the VSC to improve the system stability has been reported [9].

Table 1 Generation and Mean f(x).

Generation	f-count	Mean f(x)	Stall f(x)	Stall Generations
1	80	4.85E-05	0.007635	0
2	120	4.85E-05	0.003482	1
3	160	4.72E-05	0.001534	0
4	200	4.63E-05	0.000625	0
5	240	4.63E-05	0.000205	1
6	280	4.63E-05	0.00012	2
7	320	4.63E-05	0.001053	3
8	360	4.63E-05	0.001891	4
9	400	1.99E-05	0.001372	0
10	440	1.98E-05	0.002357	0
11	480	1.98E-05	0.001779	1
12	520	1.97E-05	0.001698	0
13	560	1.97E-05	0.001173	0
14	600	1.95E-05	0.000634	0
15	640	1.9E-05	5.93E-05	0
16	680	1.9E-05	2.02E-05	0
17	720	1.87E-05	1.94E-05	0
18	760	1.83E-05	1.92E-05	0
19	800	1.81E-05	1.9E-05	0
20	840	1.81E-05	1.87E-05	1
21	880	1.81E-05	1.85E-05	2
22	920	1.81E-05	0.001139	0
23	960	1.8E-05	0.000573	0
24	1000	1.79E-05	0.000136	0
25	1040	1.78E-05	8.88E-05	0
26	1080	1.78E-05	1.8E-05	0
27	1120	1.78E-05	1.79E-05	1
28	1160	1.78E-05	1.78E-05	2

29	1200	1.77E-05	0.000504	0
30	1240	1.77E-05	6.69E-05	1
31	1280	1.77E-05	6.68E-05	0
32	1320	1.77E-05	1.78E-05	0
33	1360	1.76E-05	1.77E-05	0
34	1400	1.76E-05	1.77E-05	0
35	1440	1.76E-05	1.77E-05	0
36	1480	1.76E-05	1.76E-05	0
37	1520	1.76E-05	1.76E-05	0
38	1560	1.76E-05	1.76E-05	0
39	1600	1.76E-05	1.76E-05	0
40	1640	1.76E-05	1.76E-05	1
41	1680	1.76E-05	1.76E-05	0
42	1720	1.76E-05	1.76E-05	0
43	1760	1.76E-05	1.76E-05	1
44	1800	1.76E-05	1.76E-05	0
45	1840	1.76E-05	1.76E-05	1
46	1880	1.76E-05	1.76E-05	2
47	1920	1.76E-05	0.000309	0
48	1960	1.76E-05	0.00026	1
49	2000	1.76E-05	0.00026	2
50	2040	1.76E-05	0.001305	0

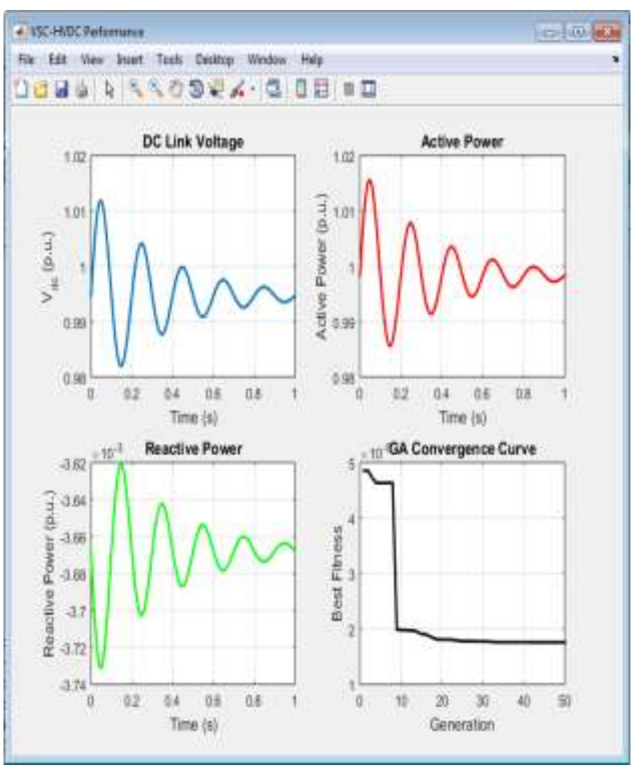

Fig. 4: GA optimization of dc link and Power.

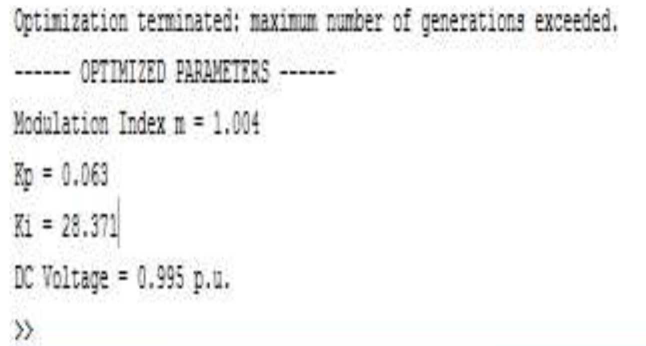

Fig. 5: KP and KI Optimize values.

X. CONCLUSION AND FUTURE SCOPE

In the forthcoming work, the covariance matrix adaptation method which adapts the resulting search distribution to the contours of the objective function by updating the covariance matrix deterministically using information from evaluated points will be applied to the GA to hopefully reach better performance and to ensure the optimal controller robustness against all types of uncertainties and faults even those for which the GA is susceptible.

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