HARMONIC IMPACT OF DG CONFIGURATION IN DISTRIBUTION SYSTEM

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ABSTRACT

With more and more DGs used in distribution network, it is important for reliable and optimal operation of the distribution system after DGs connected into the system .This work studies the harmonic impact of DG. On this base, it optimizes the site and size of DG through improved multi-objective particle swarm optimization (MOPSO) algorithm.

DG is classified as linear model and nonlinear model is this work from the harmonic analysis perspective. For harmonic flow calculation of distribution system with DG, calculation model of DG is established and decoupled algorithm for harmonic flow calculation is introduced. In theory, the rule of THD (Total Harmonic Distortion) variety is deduced when two types of DG access to an ideal distribution network with the different site and size.

The particle swarm algorithm (PSO) is improved by linear adjustment of inertia weight and introducing an item in formula of updating particle's velocity to form a hybrid PSO model. Then MOPSO algorithm with bidirectional searching strategy is proposed mixed optimal solution and isolated point search. Combining the improved MOPSO algorithm with fundamental and harmonic power flow can solve DG optimization configuration of multi-objectives constraints and integer optimization. Reasonable planning of DG can not only effectively decrease THD and power loss of distribution network but raise the voltage level also.

INTRODUCTION

With the growing consumption of the electric power, DGs have been concentrated and will be widely used in the near future. The impact of DG on power system is now paid more and more attention. The Influence of harmonic distortion after adding DG is an important problem in the field of power energy utilization. Most DGs, like fuel cells, micro-turbine, wind turbine, can only be connected to power system after transformation by power electronic facilities. Moreover, the sustained growth of nonlinear power load, especially the widely use of static power converters, can lead to voltage and current distortion and harmonic pollution. So harmonic impact of DGs should be studied to guarantee the reliable and optimal operation of distribution system after DG connected into the system.

HARMONIC ANALYSIS OF DISTRIBUTION SYSTEM WITH DG

Harmonic limit of power system is defined in GB/T14549-93, "The network harmonics and the quality of public utility", which is a national standard for power system harmonics in China. Limits of harmonic voltage and harmonic current are provided in standard in details. For harmonic voltage and harmonic current, two indices are important for measurement.

(a) content rate of each harmonic voltage(current)

$$\mathrm{HRV}_n = \frac{V_n}{V_1}\times 100\% \quad \mathrm{HRI}_n = \frac{\mathrm{I}_n}{I_1}\times 100\% \qquad (1)$$

Where V_n , I_n represent effective value of nth harmonic voltage (current). V_1 , I_1 represent effective value of fundamental voltage e(current) .

(b) total distortion rate of harmonic voltage(current)

$$THD_V = \frac{\sqrt{\sum_{n=2}^{N} V_n^2}}{V_1}\times 100\% \quad THD_I = \frac{\sqrt{\sum_{n=2}^{N} I_n^2}}{I_1}\times 100\% \qquad (2)$$

POWER FLOW CALCULATION OF DISTRIBUTION SYSTEM WITH DG

Calculation Model of DG

When DGs connected into, the distribution system will be changed from a radial passive network to an active network with small or medium generators. Because of the particularity of DG, the model adopted in power flow calculation is different from traditional generators. PQ node, PV node or balance node is adopted in traditional flow calculation, but the node type of DG cannot be determined for the uncertainty of operation manners and control characteristics.

Usually, DG can be viewed as a constant active power source for it does not concern frequency regulation when connected into the system. Reactive power and operation voltage of DG should be determined upon the capacity, generation form and connection mode. The connection interface of DG to the distribution system is consisted of three forms.

(a) Synchronous generator connection interface

This interface includes two methods: voltage control and power factor control. DG with voltage control can maintain the voltage by voltage regulator and can be considered as PV node in flow calculation, while DG with power factor control can maintain the power factor and can be viewed as PQ node.

(b) Asynchronous generator connection interface

Asynchronous generator has no excitation control system and establishes the magnetic field by the reactive power supplied from the distribution network. So asynchronous generator has no ability on voltage regulation and cannot be considered as PV node. The reactive power is closely related with the node voltage of the generator, and can be viewed as PQ(V) node, that is, reactive power Q is subject to voltage V. In the iterative process of flow calculation, Q should be updated using V obtained in the last iteration.

(c) Power electronic equipment connection mode

Some DGs like fuel cells, photovoltaic energy system and micro-turbine should be connected to the system after transformation of power electronic equipments such as DC/AC, AC/DC/AC and AC/AC. This mode of DG is determined by the control strategy of the converter, including voltage control converter and current control converter. DGs, like fuel cells and micro-turbine, which are connected to the system via voltage control converter can be regarded as PV node in flow calculation. Those connected via current control converter is viewed as PI node, for example, photovoltaic energy system and storage batteries.

Improved Back/forward sweep method

Back/forward sweep method is now widely used in power flow calculation of distribution network. Considering the limits of the back/forward sweep for solving PV node and meshed network, improved back/forward sweep method is adopted in this work. Power correction equations are put up based on resistance matrix, reactance matrix and mismatch of voltage magnitude. Flexible nodal numbering scheme is put up in the improved method and is more suitable for distribution system with DGs. Detailed derivations and procedures can be referred to document [5].

HARMONIC FLOW CALCULATION OF DISTRIBUTION SYSTEM WITH DG

Constant-current source model of harmonics

Harmonics in power system mainly include many kinds of nonlinear load, such as rectifier equipments, regulating equipments, arc furnaces. Harmonic characteristics of distribution system (frequency, amplitude and phase angle) are closely related with nonlinear load. Usually, power electronic devices are the main source of harmonic current distortion. The rate of harmonics is determined by the characteristics and working conditions of the devices and has little relation with harmonic voltage distortion. So harmonic source can be approximately regarded as constant-current source, which is a simple and common model for calculation. The influence of harmonic voltage on the harmonic injecting current can be ignored.

Decoupled algorithm for harmonic flow calculation

Decoupled algorithm for harmonic flow calculation is based on the linear harmonic flow algorithms and the nonlinear harmonic flow algorithms. The main principles include:

(a) Changing from simultaneous iteration of fundamental power flow with harmonic flows (in conventional non-linear algorithms) to separated iteration.

(b) Fundamental power flow is iterated and solved by Newton method, while harmonic flow is solved by Gauss elimination.

(c) The two methods are related by power equations and the interaction between the fundamental and the harmonics is accordingly considered.

The algorithm has some characteristics such as improving the calculation accuracy, reducing the amount of calculation, saving the calculation memory, increasing the calculation speed and ensuring the convergence of the results.

IMPACT ON HARMONIC DISTRIBUTION WITH DG CONNECTED

Chain type distribution system (see Fig1) is adopted as the analysis model and PCFLO software is utilized for simulation analysis of power system harmonics in this work. PCFLO can analyze power harmonics via frequency domain and get amplitude and initial phase angle based on Fourier decomposition. Each index about harmonic level such as total distortion rate of harmonic voltage THD_V and total distortion rate of harmonic current THD_I can be obtained more direct and conveniently. The soft version used in this work is V6.0.

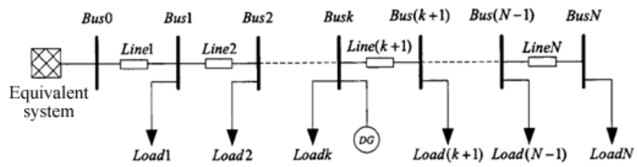

Fig1. Chain type distribution system model

IMPACT BY LINEAR MODEL DG

When linear model DGs are connected to the system, capacity and placement of DGs are two main impacting factors for harmonic analysis. From actual simulations, some conclusions can be drawn as follow.

(a) Connections of linear model DGs can reduce the distortion level of harmonic voltage. The voltage level and total distortion rate of harmonic voltage THD_V of a feeder line are determined by the total output of DG when the connection place of DG is kept unchanged. The bigger the total output is, the higher the voltage level will be and the smaller THD_V of the nodes along the feeder line will be (the precondition is the voltage cannot exceed the upper

limit).
(b) The voltage level and THD_V along the feeder line is determined by the connection place of DG when the output of DG is kept unchanged. When DG is connected near the end of the feeder line, the total voltage level of the feeder line will be higher and THD_V of the nodes along the feeder line will be smaller. Otherwise, When DG is connected near the bus, the total voltage level of the feeder line will be lower and THD_V of the nodes along the feeder line will be bigger.
So when to reduce total distortion rate of harmonics, linear model DG should be placed at the end of the feeder line better. Increasing the output of linear model DG properly can also reduce the distortion rate of harmonic voltage when the voltage of each node does not exceed the limit.

IMPACT BY NONLINEAR MODEL DG

When nonlinear model DGs are connected to the system, we can get some conclusions from actual simulations.
(a) THD_V along the feeder line is determined by the total output of DG when the connection place of DG is kept unchanged. The larger the output is, the higher THD_V of the nodes along the feeder line will be.
(b) When the output of DG is kept unchanged, THD_V of the nodes before the connection place will be bigger and after the place will be smaller if the connection place of DG is near to the bus.
Connections of nonlinear model DGs can increase the distortion rate of harmonic voltage. For reducing the distortion rate, DG is not recommended to be connected to the end of the feeder line and can be placed at the middle of the line and a little near to the bus.

DG CONFIGURATION BASED ON IMPROVED MOPSO ALGORITHM

BASIC PARTICLE SWARM OPTIMIZATION (PSO) ALGORITHM

Particle swarm optimization (PSO) is a kind of heuristic algorithm based on swarm intelligence. PSO algorithm simulates the action of the bird swarm looking for food by flying and gets the optimization through the cooperation in the bird swarm. For its easy implementation, low requirement and cheap cost, PSO has used in wide engineering fields. PSO can be conveniently applied to solve complicated nonlinear, noncontinuous, multi-dimensioned optimization problem with discrete variables and multiple restrictions. There is a large amount of such problem in modern electric power systems.
But PSO also has its shortages. This algorithm is easy in premature convergence or become stagnant during the optimizing process. This is because every particle’s speed can not be refreshed in the anaphase of the optimization, which cause the particles to collect together very tightly in some locations and can not make the local search more wide and meticulous. Fast convergence of PSO will result in the local optimum. Premature convergence is caused by the rapid loss of diversity within the swarm. So when adopting PSO to solve multi-objective problems, it is important to promote the diversity of population.

MULTI-OBJECTIVE OPTIMIZATION MODEL

According to the influence of DG on the harmonic analysis of distribution system, two optimization objectives are adopted in the work with the remise condition that all the constraints can be met.
Objective1: From the harmonic analysis with DG, minimizing the total distortion rate of harmonic voltage THD_V, expressed as

$$\min \mathrm{F}_1 = \sum_{i=1}^{N} THD_{Vi} + \mathrm{C}_1\delta_1 + \mathrm{C}_2\delta_2 + \mathrm{C}_3\delta_3 + \mathrm{C}_4\delta_4 + \mathrm{C}_5\delta_5 \tag{3}$$

Objective2: Connection of DGs will import impacts on the structure and operation of distribution network. An important part is the influence on the network loss. This objective is to minimize the active power loss of the distribution network.

$$\min \mathrm{F}_2 = \sum_{l=1}^{M} P_{loss(l)} + \mathrm{C}_1\delta_1 + \mathrm{C}_2\delta_2 + \mathrm{C}_3\delta_3 + \mathrm{C}_4\delta_4 + \mathrm{C}_5\delta_5 \tag{4}$$

Where $\mathrm{C}_1\delta_1,\ldots,\mathrm{C}_5\delta_5$ are penalty terms.
This is an optimization problem relating large-scale space searching. PSO algorithm is suitable for solving these problems. An improved PSO algorithm is proposed for utilization in the DG configuration in distribution system.

IMPROVED MOPSO ALGORITHM

Basic PSO algorithm has its shortages such as premature convergence and trapped in local optimum. [7] In this work, an improved multi-objective particle swarm optimization (MOPSO) algorithm with bidirectional searching strategy. The algorithm is improved by linear adjustment of inertia weight and an item in formula of updating particle's velocity is introduced to form a hybrid PSO model. Optimal solution and isolated point search are combined in the algorithm for solving DG optimization configuration of multi-objectives constraints and integer optimization. [8]

APPLICATION OF IMPROVED MOPSO ALGORITHM IN DG CONFIGURATION

Combining MOPSO algorithm with fundamental and harmonic power flow, optimal connection position and capacity can be obtained to minimize THD and active power loss. Fig2 is the flow chart of the actual application of improved MOPSO algorithm in DG configuration.

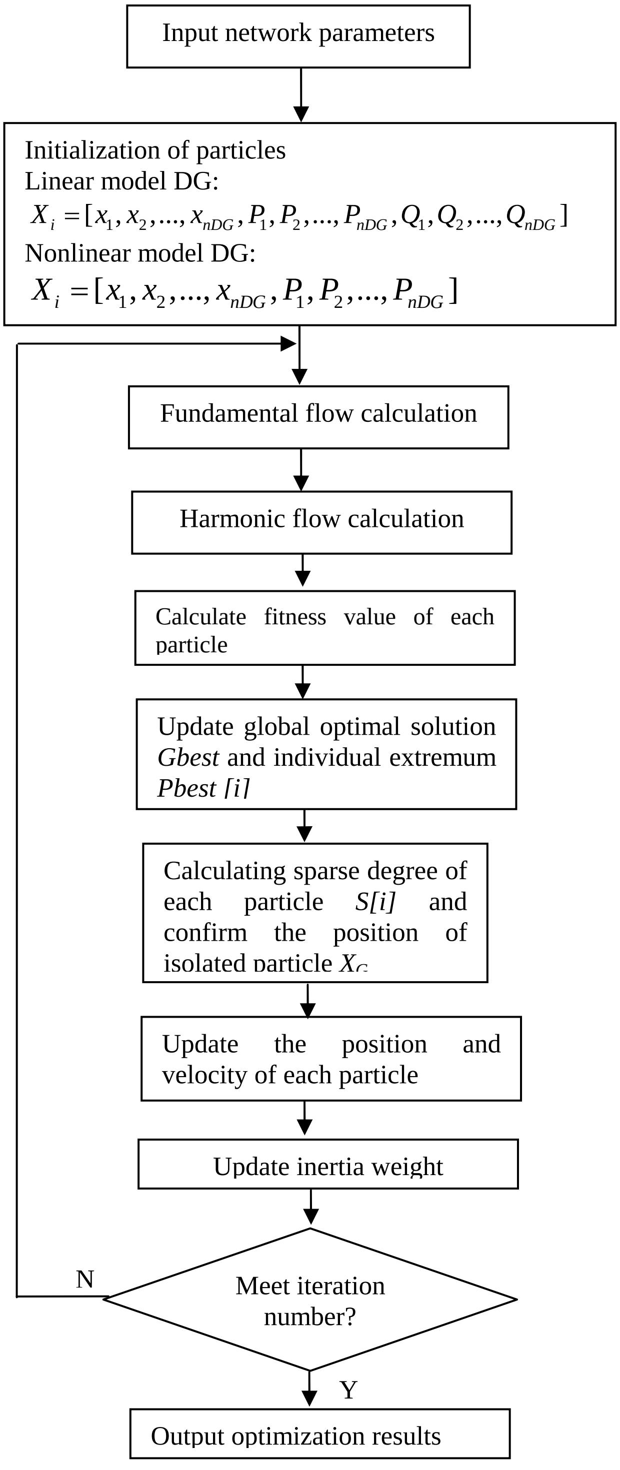

Fig2 Flow chart improved MOPSO algorithm applied in DG configuration.

CONCLUSIONS AND PROSPECTS

Improved back/forward sweep flow algorithm, decoupled harmonic power flow calculation and improved MOPSO algorithm are suitable methods for DG configuration in distribution network. Reasonable configuration of DG can not only decrease THD and power loss of distribution network but raise the voltage level also.

Impact of DG connection on the distribution network is now still a new researching field. In the construction of the harmonic model of DG, assumptions and simplifications have been done in this work. Some problems should be studied in the future work.

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