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DG Allocation in Distribution Network Using ILC Method

[1]Mehdi Ahrari Nouri, [1]Ahmadreza Argha, [1]Zahra Maghsoodzadeh Sarvestani and [2]Mehdi Roopaei

[1]Sama Technical and Vocational Training College, Islamic Azad University, Shiraz Branch Shiraz, Iran
[2]Department of Electrical Engineering, Science and Research Branch, Islamic Azad University, Fars, Iran

Abstract: This paper presents a new method to calculate the optimal size and location for DG placement in order to minimizing the total power losses in distribution systems. The new method is named Iterative Learning Method (ILC) and is based on the objective function in which considers the elect of size and location of DG with respect to loss in the network. The proposed procedure was tested and validated in three distribution test systems with varying size and complexity. Results obtained from the proposed methodology are compared with similar works and different methods. Our results show that the loss sensitivity factor based approach may not lead to the best placement for loss reduction.

Key words: Distributed generation · Optimum size and location · Distribution system

INTRODUCTION

Using distributed generation (DG) in power system growing rapidly in the last few years. Increasing the power demand by customers due to the lack of energy sources can be lead to many problems. Many approaches were tested to solve this problem by now; the usage of compensators like capacitors, enhancement the capacity of overhead power lines (OHL) by FACT devices, employment the voltage regulators along the feeders are some of these solutions, but by improvement the technology of small scale power sources such as fuel cells, photovoltaic, wind power, micro turbines, internal combustion engines the a great solution can be adding these small power suppliers directly to the power system to feed the demand of energy. DG can cause the great improvement in power system parameters; improving reliability, efficiency and power-quality, alleviates the system constraints and reduction the energy cost is some of these benefits [1].

As mentioned in [2], there is no standing international definition for DG and every country according to its bulk system define the characteristics of DG.

Some definition for distributed generation is given in [3]. Distributed power sources have some characteristics in common:

- Their rating is small compared to conventional power plants.
- They are often privately owned.
- They are not centrally dispatched.
- They are connected to MV or LV distribution networks.
- They do not contribute to frequency or voltage control.
- They were not usually considered when the local grid was planed.

The distributed generators can be added to any voltage levels of the bulk system, but it is obvious as much as these suppliers be closer to the users there efficiency be better and the cost of energy production will be reduced; so adding these DG's in distribution systems seems to be correct decision.

Along all of the positive characteristics of DG mentioned above because the power system did not designed for this kind of power suppliers form the beginning it should be effective studies on position selection of DG's and there amount of power release. In the other word improper DG allocation may cause to some difficulties; over voltages in distribution feeders, enhancement of short circuit capacity of power apparatus are some of these problems [4].

So one of the major tasks in this field is to choose the DG with the proper value and put it in the good position in the power systems.

During the last decades artificial intelligence techniques (AI) are used widely to solve these kinds of problems. AI techniques by their nature can optimize two

Corresponding Author: Mehdi Roopaei, Department of Electrical Engineering, Science and Research Branch, Islamic Azad University, Fars, Post Box: 71955-177, Shiraz, Iran.

or more goal function and simultaneously keep desire parameters in the proper ranges for example in [5] the fuzzy approch is used or in [6] the genetic algorithm along with optimal power flow is presented. The bee colony optimization is used in [7] for DG allocation.

In this paper we introduce a novel AI method named iterative learning control (ILC) that using an iterative algorithm to reach an optimize solution by doing iterative control process.

Iterative learning control (ILC) is a technique to control the systems doing a defined task repetitively and periodically in a limited and constant time interval. Examples of such systems are robot manipulators that are required to repeat a given task with high precision, chemical batch processes or, more generally, the class of tracking systems.

Motivated by human learning, the basic idea behind iterative learning control is to use information from the previous executions of the task in order to improve the performance from trial to trial in the sense that tracking error is sequentially reduced. Thus, the principle of ILCs is that, during the execution of control algorithm in the *k*th iteration, some data as errors are recorded. These are used by the learning algorithm in the execution *k+1* for improving the control inputs and progressively reducing the output errors and increasing the performance of close loop system. Finally after a number of repeated trials, them system should obtain an appropriate control input, so that this input produces the desired output.

Iterative learning control (ILC) has become the active research area for the past two decades and great efforts have been put in the development of different learning controllers. Industrial robotic operations, chemical processes are such situations where ILC can be used to improve the performance. The approach is motivated by the observation that if the system controller is fixed and if the system's operating conditions are the same each time it executes, then any errors in the output response will be repeated during each operation. These errors can be recorded during system operation and can be used to compute modifications to the input signal that will be applied to the system during the next operation, or trial. In ILC, refinements are made to the input signal after each trial until the desired performance level is reached.

Fig. 1 illustrates the basic configuration of ILC, where $u_k(t)$ the input signal during the *k*th iteration applied to the system produces the output trajectory $y_k(t)$ and $y_d(t)$ denotes the desired trajectory, which the system should track. These signals are stored in the memory until the current (*k*th) iteration is over, at which time they are processed offline by the ILC algorithm. The learning controller compares $y_d(t)$ and $y_k(t)$ and adds an update term with $u_k(t)$ to produce $u_{k+1}(t)$, the refined input signal given to the system for the (*k+1*)th iteration. The above signals/trajectories are functions of time defined on a finite interval $t\in[0,T]$ and updates occur sequentially in time up to the required error goal is reached. D-type ILC algorithm was introduced by Arimoto *et al*., (1984), as a first work on ILC is of the form $u_{k+1}(t) = u_k(t) + \Gamma\dot{e}(t)$, where the derivative of the tracking error is defined as $\dot{e}(t) = \dot{y}_d(t) - \dot{y}_k(t)$ with a suitable learning gain G. Bondi *et al*., (1988) set the learning controller with a sufficient linear feedback, which is shown to ensure the tracking performance. Further research on ILC led to the development of new algorithms and their implementation issues with the existing conventional feedback controllers (Atkeson and McIntyre, 1986, Kuc *et al*., 1991, Jang *et al*., 1995). The capability of ILC for varying environments and modeling errors has been explained in Moore (1998). As an extension to the first-order systems, higher-order ILC for a class of nonlinear dynamic systems was reported in Bien and Huh (1989). It uses more historical data to get the better output tracking performance. Stability analysis of learning control scheme with disturbances and uncertain initial condition were discussed by Heinzinger *et al*., (1992). Some of the nonlinear robust, adaptive and model based ILC algorithms are also addressed by Xu and Tan (2003), Tayebi (2004) and Bukkems *et al*., (2005). Applications of ILC algorithms are applied for the robot including its actuator dynamics and for direct drive robots are explained in (Gopinath and Kar, 2004, Bukkems *et al*., 2005). The detailed survey of research progress in ILC area can be found in (Bristow *et al*., 2006). The advantage of ILC is that it does not require the knowledge about the system dynamics and learning starts as iteration progress. This results in large initial errors in the early stage of iterations and very slow convergence of tracking error as the iteration number $k\rightarrow\infty$.

As can be seen in ILC methods an error signal is minimized sequentially in order to trace a desired value. As a result this algorithm can be used as an optimization method.

At section 2 we introduce the problem formulation and mathematical relations and goal function and then in section 3 the ILC method will be well described. In section 4 the proposed method will be described and tested in some standard power system test cases to indicate the robustness of our method and finally in section 5 the conclusion will be presented.

Problem Formulation: DG placement in distribution system should be done so that electrical parameters such as voltage profile, power loss index and power quality are improved. In this paper the allocation of DG is proposed based on minimization of power losses and the constraints of voltage should be satisfied.

The formulation of problem can be written as:

$$Minimize\{(K_P \times (\sum_{i=0}^{N-1} P^k_{loss(i,i+1)}) \tag{1}$$

Such that:

$$P_{gi} - P_{di} - V_i \sum_{j=1}^{N} V_j Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) = 0 \tag{2}$$

$$Q_{gi} - Q_{di} - V_i \sum_{j=1}^{N} V_j Y_{ij} \sin(\delta_i - \delta_j - \theta_{ij}) = 0 \tag{3}$$

$$V_i^{\min} \le V_i \le V_i^{\max} \quad i = 1...N \tag{4}$$

$$P_G^{\min} \le P_{G_i} \le P_G^{\max} \quad i = 1...N \tag{5}$$

Where:

K_P, Cost per power loss, \$/kW/year
N, Total Number of buses in radial distribution network.
$P^k_{loss(i,i+1)}$, Active power loss of (i, i+1) branch
P_{gi},Q_{gi} Active and reactive power generations at bus i
P_{di},Q_{di} Active and reactive power load at bus i
V's, δ's, System bus voltages magnitudes and phase angles.
Y_{ij},θ_{gi} Bus admittance matrix elements
V_i, The voltage of bus i.
$V_i^{\max}$, Maximum allowable voltage in bus i.
$V_i^{\min}$, Minimum allowable voltage in bus i.
P_{Gi}, Total injected KW of connected DG in bus i.
$V_G^{\max}$, Maximum allowable KW for DG.
$V_G^{\min}$, Minimum allowable KW for DG.

This objective function considered here in equation (1) denotes the cost of power loss. Equations (2) & (3) show the load flow restrictions of power system. The security and operational constraint of voltage profile and DG's have been formulated in inequality of (4) and (5).

Iterative Learning Control Method: The repeatable control environment implies an identical target trajectory and the same initialization condition for all repeatable control trials. Many existing control methods are not able to fulfill such a task, because they only warrant an asymptotic convergence and being more essential, they are unable to learn from previous control trials, whether succeeded or failed, without learning, a control system can only produce the same performance without improvement, even if the task repeats consecutively, ILC was proposed to best meet this kind of control tasks. The idea of ILC is straightforward: use the control information of the preceding trial to improve the control performance of the present trial. This is realized through memory based learning. Figure 1 shows one such schematic diagram.

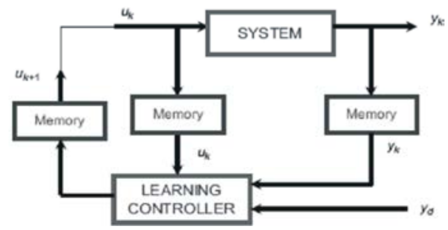

Fig. 1: A typical ILC

Where, the subscript k denotes the *k*th control trial. Assume that the target trajectory, $y_d(t)$ is repeated over a fixed time interval and the plant is deterministic with exactly the same initialization condition. Suppose that the perfect output tracking is achieved at the *k*th trial. The feedback loop is equivalently broken up. $u_k(t)$ who did the perfect job will be preserved in the memory for the next trial. In the sequel $u_{k+1}(t) = u_k(t)$, which warrants a perfect tracking with a pure feed forward.

The simplest ILC problem:
For a given process

$$y(t) = g(t)u(t) \tag{6}$$

Where $g(t) \neq 0$ is defined over a period [0,T], find the control input, u(t), such that the target trajectory

$$y_d(t) \quad \forall t \in [0,T] \tag{7}$$

can be perfectly tracked. Without loss of generality we assume that $y_d(t)$ and g(t) are bounded functions.

We can directly acquire the desired control signal without any parametric or function identification. This will make the control system more efficient and avoid extra error incurred by any intermediate computation, e.g. a large numerical error may occur if g(t) takes a very small value at some instant t and is inverted. If the control task runs once only and ends, we are not able to directly achieve the desired control signal. When the same control task is repeated many times, we can acquire the control signal iteratively by the following iterative learning control scheme.

$$u_{k+1}(t) = u_k(t) + q\Delta y_k(t) \quad \forall t \in [0,T] \tag{8}$$

Where the subscript $k \in Z_+$ is the iteration index, $Z_+ = 0,1,2,..$ is the set of non-negative integers. $u_0(t)$ can be either generated by any control method or simply set to be zero. q is a constant gain and $\Delta y_k(t) = y_d(t) - y_k(t)$ is the output tracking error sequence.

There are two ways we can prove the convergence, either $\Delta y_k(t) \to 0$, or $\Delta u_k(t) = u_d(t) - u_k(t) \to 0$, when $i \to \infty$. For simplicity we will omit the time *t* for all variables from *0* to *T* if not otherwise mentioned.

On the other hand, it is of great importance to realize that ILC algorithm can be used as an optimization method. In this regard to find the best position and the best quantity of DG in a distribution system in a way that electrical parameters such as voltage profile, power loss index and power quality are improved. For this reason the error signal which should be minimized.
Can be introduced as follows:

$$Error^k = -P^k_{loss} \tag{9}$$

Where, the subscript *k* denotes the *k*th trial. As it was mentioned previously to produce the corrective term the relation (10) should be used. This relation can be rewritten as follows:

$$P_{gi}^{k+1} = P^K_{Gi} + learning\ factor.\ Error^k \tag{10}$$

The subscript *i,* as it was mentioned previously denotes the selected bus which the proper DG is located.

One of the most important problems which should be solved is to find a way to select the appropriate bus where the DG should be located. In other words, we should select a bus that with the minimum amount of active injected power the maximum amount of reduction in power losses is obtained. The proposed algorithm of this article is introduced in the following section. As it will be shown in the following section this method is very effective and powerful in comparison with other previous proposed methods.

Implementation the ILC Method: In this section a new ILC method is described to find the optimum size and location of DG in distribution systems.

The condition of DG allocation requires the operational constraints to be satisfied. The first restrict is the convergence of load flow. In this paper the direct power flow algorithm [8] is used. This algorithm introduces a direct approach by using a bus-injection to branch-current matrix (BIBC) and a branch-current to bus-voltage matrix (BCBV) for calculating the voltage of buses. This algorithm can be used in normal and unbalanced three phase distribution systems.

The proposed ILC method can be written as follow:

Step 1: Choose the random initial value of DG on bus number i.

Step 2: Run the load flow and calculate the error equation (9).

Step 3: Update the value of DG by using relation (10).

Step 4: Calculate the total power loss of the power system.

Step 5: Repeat the algorithm from step 2 until the power loss decrease stopped.

Step 6: Print the value of DG with the minimum amount of total power loss in all buses.

One of the other important restrictions is the range of allowable voltage of each bus that should to be in proper values. The ranges of voltages are set to be 0.95 and 1.05 per unit.

Test Systems and Results: In order to evaluate the ILC method, it should be tested in some test cases, so three distribution systems with different sizes that have been used in other papers are selected. These case studies are as follow:

9-Bus System: The 9-bus radial distribution feeder of [9] is taken as the first test case. The rated voltage is 23 kV and the system is shown in Fig. 4.

The total active and reactive load of the system is 12.38 MW and 4.186 MVAR and the biggest load is placed in bus 2 by the size of 1.84 MW.

In the base case the maximum and minimum bus voltages are o.9929 and 0.8375 per unit respectively and the total active power loss is 783.77 KW. It is clear that the voltage profile is not in proper value according to relation (4) and that is because of heavy loading of the system.

The results of optimum DG allocation are shown in following figures.

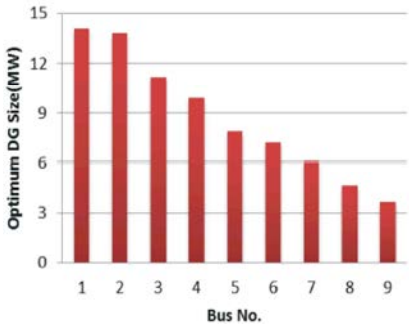

Fig. 2: The optimum size of DG in case study 1

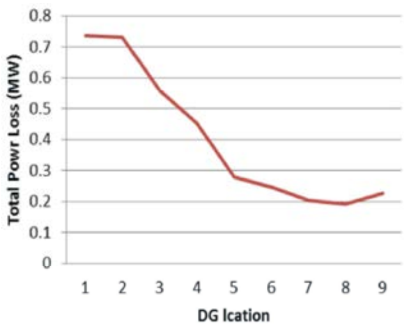

Fig. 3: The total power losses in case study 1

As it is shown in Figure 3 the best position of DG is bus number 8 that has the lowest value of total power loss. The size of DG in this bus is calculated equal to 4.6050 MW. After the DG injecting of power to system the minimum voltage is 0.9552 per unit and the power loss is 192.21 KW. These values show the positive effect of DG in this heavy loaded distribution system.

2.33-Bus System: This test case has 33 buses and 4 lateral branches, the nominal voltage of 12.66 KV and total load of 3.715 MW and 2.3 MVAR [10]. The upper and lower values of bus voltages before DG allocation are 0.9970 and 0.8926 per unit and the total power losses are 211.79 KW and 235.71 KVAR.

In Figures 4 and 5 the results of ILC method of DG allocation are plotted.

In Figure 5 it is see that the best position of DG is bus 12 and the second position is for bus 14. For the location of DG in bus 14 with the size of 2.5695 MW the total power loss is equal to 108.62 KW.

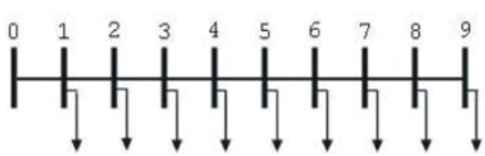

Fig. 4: The Optimum DG size in 33-bus system

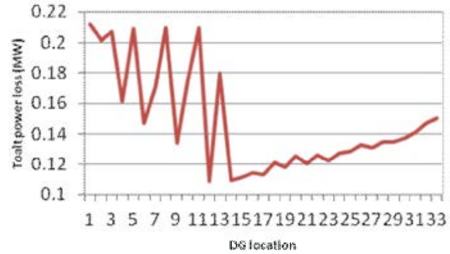

Fig. 5: The total power losses in case study 2

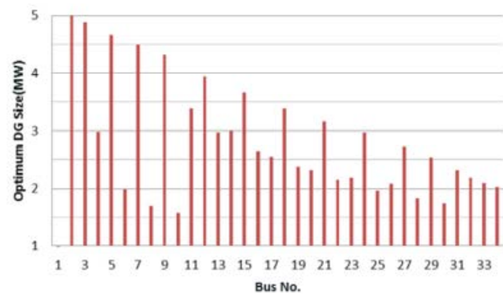

Fig. 6: The Optimum DG size in case study 3

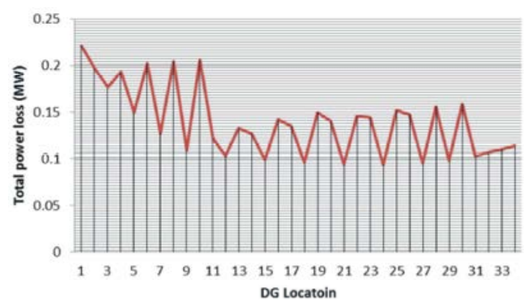

Fig. 7: The total power losses in case study 3

3.34-Bus System: The last case study is a radial distribution network with 34 buses. The data of this test system has been taken from reference [9]. The system voltage is 11 kV and the total loads are 4.6365 MW and 2.8735 MVAR. Before any compensation, the, the active and reactive losses are 221.72 kW and 65.11 KVAR, respectively and the voltage limits in per unit are 0.9941 and 0.9417.

The result of ILC method for 34-Bus system is illustrated in Figures 6 and 7.

The best position and value for DG in this system are bus 24 and 2.9676 MW. The corresponding total power loss of this size of DG is 93.74 KW.

In Table 1 the summary of simulated results is shown.

Comparison: In order to compare our ILC method with the other similar works, two papers with the same case study is selected. In paper [11] one of test cases is 33-Bus system and in [12] the 34-Bus system is the same case

Table 1: Summary of simulation results

			Power loss (KW)	
Case study	Optimum location	DG size (MW)	Without DG	With DG
9-Bus	Bus 8	4.605	783.77	192.1021
33-Bus	Bus 12	2.5695	211.79	108.62
34-Bus	Bus 24	2.9676	221.72	93.74

Table 2: Comparison among ILC method and [11]

33-Bus	Optimum location	DG size (MW)	Power loss (KW)
ILC method	Bus 12	2.5695	108.62
Ref [11]	Bus 6	2.4900	111.24

Table 3: Comparison among ILC method and [12]

34-Bus	Optimum location	DG size (MW)	Power loss (KW)
ILC method	Bus 24	2.9676	93.74
Ref [12]	Bus 21	2.8848	99.00

study as our work. In these papers the analytical method is used to calculate the size of suitable DG and by using loss sensitivity factor a proper bus is selected.

In Tables 2 and 3 the comparisons are done. In these tables the results of ILC method of this paper and the method presented in [11, 12] are compared. As it is seen in both case studies the ILC method has a better result in reducing the total power loss.

CONCLUSIONS

This study introduces and evaluates a new ILC method for optimum placement of DG in distribution systems.

Allocation of DG should be done along with many important factors of distribution system such as power quality and loss power. These constraints are considered and take in account in this method.

The method developed herein is tested on different distribution systems and the results have been compared with similar research works.

The comparison shows the effectiveness of the proposed method in case of lower total power loss that is the major factor in our study.

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