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Optimal scheduling of dispatchable distributed generation in smart environment with the aim of energy loss minimization

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ABSTRACT

It is obvious that the high accurate information of network conditions in smart grids definitely leads to high efficient performance of the network. This paper discusses how much is the effect of smart grid compared to conventional networks to the daily energy loss minimization. In other words, the question of “is it worth to move towards the smart environment?” is discussed from only an aspect point of view in the paper. For this purpose, an optimal management of Dispatchable Distributed Generation (DDG) in smart grid with the aim of daily energy loss minimization is performed and fairly compared to DDG optimal management in conventional distribution networks. The effect of suboptimal performance of the system in conventional networks is economically analyzed. A 3-level load profile which is forecasted in advance is taken into account as the load profile of the conventional network. This load profile is investigated in 5 different scenarios from prediction points of view. On contrary, the load profile of the network in smart environment is considered as a 24-h load profile which is achieved using smart metering devices. To show how the smart grid impressively affects the network performance regards to conventional network, the DDGs are also programed in order to minimize the voltage deviation of the network. The economic analysis and yearly benefit of loss reduction are also conducted in both situations (smart grid and conventional network). In addition, the performances of the conventional network and smart grid are evaluated in two other phases i.e., in the presence of renewable energy resources and encountering with disturbances. The study is applied on 69-bus radial test system which is used in many previous studies. The results show the detrimental effects of suboptimal operation of the system on network performance in the case of conventional networks. Moreover, the impressive impacts of smart environment on energy loss reduction and voltage profile improvement in distribution systems can be concluded from the results. Furthermore, the study shows how the smart environment can be useful for utilization of renewable energy resources and managing the disturbances.

1. Introduction

Growing trend of electricity energy consumption which is mainly produced by fossil fuel burning results in different issues such as environmental and financial problems [1]. On the contrary, nearly 15% of active power which is generated in large power plants wasted through different apparatuses mainly in distribution networks [2]. Since the energy losses reduction may results in alleviating the foregoing problems, power losses reduction is one the most interesting issues in power system studies.

There are different methods for loss minimization in power systems in the level of both transmission and distribution network such as Reconfiguration of distribution networks [3], capacitor banks placement [4], FACTS devices placement [5,6], and Distributed Generation (DG) placement [7,8]. Among different methods, DG placement is one of the most attractive methods because of the benefits such as reliability improvement, voltage profile improvement and active power selling. However, insufficient placement and scheduling of DG can result in detrimental performance.

On one side, optimal DG allocation can be implemented for all kinds of DG and performed in the phase of design using general information of the networks mostly the worst conditions of the systems (for instance peak load situation). On the other side, DG

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Nomenclature

R_i	Resistance of feeder i
$Limit_i$	Thermal limit of feeder i
L_i	Length of feeder i
OF	Objective Function
P_{loss}	Active power loss
$P^{total}_{loss,peak}$	Total active power loss of the network in peak load situation
P_D	Active power consumption of load demand
$Load_{peak}$	The amount of peak load
Q_D	Reactive power consumption of load demand
t	Time step (here an hour)
U	Amplitude of bus voltage
T	Total time duration (here a day)
G	The location of DDG
$P^{total}_{loss,t}$	Total active power loss of the network at time step t
P_{DG}	Active power generation of DDG
$Load_t$	Total amount of load demand at time step t
Q_{DG}	Reactive power generation of DDG
x	Decision variables
$_{LR}$	the amount of loss reduction after DDG placement in the network
g	Equality constraints
F_i	The Power flowing at feeder i
h	Inequality constraints

programing can be only implemented for Dispatchable kinds of DG (DDG) such as Fuel Cells, Micro turbines, and Diesel Generators. It should be mentioned here that DGs can be categorized into two main categories as dispatchable and non-dispatchable. Dispatchable DGs such as Micro Turbine, Gas Engine, and Fuel cell, are the sources which the output can be controlled by the operators. The other ones are the producers which the output cannot be controlled. Wind Turbine, and Photovoltaic are two well-known non-dispatchable kinds of DGs. The optimal operation of DDG depends on the network conditions and varies with the network conditions variations. Thus, the best operation point of DDGs should be updated as the network conditions change. It is obvious that higher accurate information of network conditions results in much better performance of the DDGs.

Optimal placement and operation of DDGs can be performed using different objective functions among which loss minimization has been more interesting for researchers in the last decades [9].

There are two main approaches in the concept of loss minimization as power loss minimization and energy loss minimization. Power loss refers to an instantaneous quantity and power loss minimization means reducing the power loss in a determined situation of the network mainly peak load situation. On the contrary, energy loss is available in the time component and energy loss minimization refers to reducing the power loss in specific time duration such as a day, a week or a month. In other words, energy loss is the power loss multiplies to specific time duration. Since the network conditions are time-varying, obtaining the optimal operation point of the network based on active power loss minimization may results in suboptimal operation [7]. Thus, it is better to consider a multilevel load profile and obtaining the optimal operation point of the network based on energy loss minimization.

Multilevel load profile can be achieved by forecasting the load demand in different time durations in conventional networks. This profile can be estimated with high level of accuracy in smart grids which is equipped with advanced metering devices. The high accurate load profile of the system leads to more optimum operation of the distribution networks [10–13].

In Ref. [14], and [9] optimal accommodation and sizing of DG is performed for daily energy loss minimization in a conventional network and a smart grid, respectively. However, in the former the effect of prediction error in load profile is not investigated. In the later, the optimal operation of renewable DG for energy loss minimization is compared to optimal operation of the network obtained based upon power loss minimization in conventional networks. Based on two foregoing articles (i.e. [9,14]) there are some questions as follow:

1 Is it impossible to consider a multilevel load profile in conventional networks and achieve a multilevel generation profile for DG units?
2 What are the issues related to consideration of multilevel load profile in conventional distribution networks?
3 What does happen for loss minimization if the load profile is considered as multilevel in conventional networks?
4 How much is the difference between loss reduction in smart grids and conventional networks with multilevel load profile?
5 How much is the benefit of loss reduction if the networks move towards the smart operation.
6 Is it worth to move through smart grids?

In the current paper these questions are discussed. The effectiveness of the smart grid on the network performance is economically investigated. A fair comparison between energy loss reduction in smart grids and conventional networks by the optimal scheduling of DDGs is performed. A 24-h load profile as the actual load demand is considered for the smart grid; while, a 3-level load profile which is investigated in 5 different scenarios is considered for the conventional network. Moreover, the scheduling of DDGs is performed for voltage deviation minimization in six mentioned scenarios. Economic analyses of the results reveal how effectiveness is the smart grids regards to conventional networks. To show how the smart grid could be useful from the other aspects, the system is evaluated in two other situations i.e., in the presence of renewable energy resources and facing the disturbances.

2. Problem formulation

2.1. DG installation benefits as objective function

The presence of DG units in the distribution networks can bring valuable benefits which can be considered as the objective function for optimal placement and dispatching [15,16]. Loss minimization, power selling, reliability improvement, and voltage profile improvement are some merits of DG installation. Among different objectives, loss minimization has been studied more than the others. In this paper, loss minimization is taken into consideration as the objective function for DDG management.

2.2. Loss minimization using DG placement

DG refers to small scale resources which are installed at the point of consumption. Being close to the end users, results in reduction in line power flow and active power loss [7]. However, insufficient allocation and generation of DG may lead to poor