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A MULTISTAGE MODEL FOR DISTRIBUTION EXPANSION PLANNING WITH DISTRIBUTED GENERATION IN A DEREGULATED ELECTRICITY MARKET[*]

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Abstract– Distribution systems management is becoming an increasingly complicated issue due to the introduction of new technologies, new energy trading strategies and a new deregulated environment. In the new deregulated energy market and considering the incentives coming from the technical and economic fields, it is reasonable to consider Distributed Generation (DG) as a viable option for systems reinforcement in competition with voltage regulator devices, to solve the lacking electric power supply problem and meet the load growth requirements with a reasonable price as well as the system power quality problems. The problem of optimal placement and size is formulated in two stages; minimization of the total costs to find optimal sizing and mounting of DG with different payback time, and maximization of the social welfare to find optimal payback time. In this framework, the object function is investment costs, which are evaluated as the annualized total investment cost, plus total running cost as well as cost of Energy Not Supply (ENS) and losses. Different system conditions are assumed to indicate the effect of the system conditions on planning decision as well as the effect of DG placement on improvement of system conditions. An optimal placement, size and investment payback time is identified. The proposed two-stage model aspects of system operation and economic aspects of market operation act as good indicators for the placement of Microturbine as a common type of DG, especially in a market environment. A software package is developed for this reason, which runs each type of planning problem very fast. The proposed methodology is tested in the IEEE 30-bus test system.

Keywords– Distributed generation (DG), distribution company (DISCO), GAMS-MATLAB interface, investment payback time, microturbine, social welfare

1. INTRODUCTION

Deregulation has significantly compromised the ability of industry to maintain the balance between generation and load for various time scales throughout the system. It is intended to change the way of making long-term investment decisions. Removing energy generation from the domain of the monopoly utility companies and allowing open competition for electrical production will enable energy generators to make market-based decisions regarding where and how much generation should be built. The theory is that the free market will be more efficient, encourage more innovation, and result in fewer stranded assets when too much or the wrong type of generation is built [1]-[3].

In competitive power markets, Distribution System Companies (DISCOs) should provide a least-cost plan and should not damage the environment. In this condition, Distributed generation (DG) can play an

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increasing role in distribution system planning of the future, not only for the cost savings but also for the additional power quality [4]-[6]. DGs can also be operated to improve voltage profiles [7]-9] and power flows within the distribution system feeder to defer Transmission and Distribution (T&D) investment [10], [11]. Improvements in distribution system reliability and overall power system efficiency can be realized. For load growth with short-lived peaks that occur during extreme weather, DGs may provide lower-cost solutions than other approaches to system capacity upgrades. DG provides a means for increasing the capacity of existing distribution facilities. When considering increasing distribution system capacity, DGs can be an alternative to the new substation addition and replacing existing equipment with larger ones. A DG installed at the distribution level releases capacity throughout the system, from transmission through distribution. Transmission system losses are eliminated, and distribution system losses are reduced [8], [12]. In competitive power markets, DG competes with centralized power generation. Hence, market regulations should ensure that DG can act freely within power markets, similar to centralized generation.

To obtain good locations for efficiency and economic improvements, optimization methods can be applied. Improper placement in some situations can reduce DGs benefits and even jeopardize the system operation and condition [1], [13].

Numerous techniques and planning methods have been proposed to address the optimal DG placement and sizing in the distribution system. The object functions of these methods are usually limited to one or two items such as loss [9], [14]-[16]. Besides, several optimization tools, including artificial intelligence techniques such as genetic algorithm (GA), tabu search, ant colony, etc., are also proposed for achieving the optimal placement of DG [16], [17]. Many of these algorithms tend to drive toward local minima instead of a global minimum. This is referred to as early convergence. For example, in GA a very fit member of the population may appear early. Another drawback of GA is that this method does not guarantee finding a local or global solution, but rather finds a good solution. The best solution may never appear in any generation. Some variations are used to combat these problems such as exponential, linear transformation and linear normalization. These weaknesses will become more evident when the number of variations and parameters increases. It also takes a long time for fine-tuning. While these parameters allow the algorithm to be tuned to solve a particular problem, the problem-dependent nature of the algorithm makes it difficult to predict the performance of the algorithm in general, and practitioners often spend a significant amount of time tuning the algorithm. In recent years, many efforts have been devoted to improving traditional algorithms by changing them [16], [18] and/or hybridization of different algorithms [18], [19]. According to the above mentioned problems, the targets in this paper are:

- To consider all of the possible constraints and objects together in a multi-objective optimization model to approach more realistic results.
- To solve the optimization problem as fast as possible, even in practical distribution systems that have a large number of variations and parameters.
- To develop a user-friendly framework (software package) to be used in applicable cases by distribution system planners.

In this paper, a new two-stage methodology for optimal placement, size and investment payback time of DG as well as Synchronous Condenser (SC) and load shedding is presented to show the effects of DG on decreasing total system costs and loss, improving power quality, system voltage and line congestion in different distribution system conditions. Microturbine has been selected as a studied DG since sitting of this kind of DG has fewer environmental restrictions. In the first stage, the objective is minimization of the total costs to find optimal sizing and mounting for different investment payback times. In the next stage, the object is maximization of the social welfare to find optimal payback time. The proposed methodology is tested in an IEEE 30-bus test system.

2. MATHEMATICAL FORMULATION

A DISCO distributes the electricity, through its facilities, to customers in a certain geographical region. A DISCO is a regulated electrical utility that constructs and maintains distribution equipment. DISCOs are responsible for building and operating the electrical system to maintain a certain degree of reliability and availability. Their main function is to operate, maintain and develop the network from a technical viewpoint. DISCOs have the responsibility of responding to distribution network outages and power quality concerns. DISCOs are also responsible for maintenance and voltage support as well as ancillary services [3], [4]. On the other hand, each participated entity in the market makes planning at its own viewpoint. In a fully deregulated environment, the sale of energy to retail consumers is decoupled from the DISCO's operational responsibilities and is a separate business where different retailers can compete. The DISCO may or may not be a retailer [3], [4]. Therefore, DISCO can encourage and sign bilateral contracts with investors to install DG and/or other equipment [1], otherwise DISCO should do that [20] because of its responsibility. It is to be noted when a DISCO invests directly in DGs, that value is a direct benefit to the distribution system in its territory. When a DISCO tries to encourage others (customers or developers) to own and operate DGs, the value is to both owner and DISCO.

The methods used to solve the expansion planning problem can be divided into two categories: methods of mathematical programming and heuristic methods, including specialist systems and evolutionary algorithms [20], [21]. Among the methods of mathematical programming, the most widely used include Linear programming (LP) [22], Non-Linear-Programming (NLP) with non-linear constraints [10], and Mixed-Integer-Programming (MLP) consisting of Mixed-Integer-Linear-Programming (MILP) with linear or linearization of the constraints or Mixed-Integer-Non-Linear Programming (MINLP) with non-linear and integer decision variables constraints [23]–[25].

Since 1980, much effort has been directed toward solving the problem of planning distribution by the use of heuristic algorithms, which came to provide an alternative to mathematical programming. Heuristic methods gained attention because they can work in a straightforward fashion with nonlinear constraints and objective function; although there is no guarantee that an optimum solution can be found, especially for a large scale problem [20]. So, in this work we have decided to use mathematical programming.

In this paper, the placement problem is formulated for the new two-stage method, to minimize the total costs to find optimal sizing and sitting of Microturbine as a kind of DG with different investment payback times, and to maximize the social welfare to find optimal payback time. Payback time is the time that it takes for the investment to pay for itself, considering the discount. It is to be noted that when a Disco invests directly in DGs, that value is a direct benefit to the distribution system in its territory. When a Disco tries to encourage others (customers or developers) to own and operate DGs, the value is to both the owner and Disco.

a) Cost function minimization

In the first stage, consumer payment, evaluated as annualized total costs, is proposed as a method to identify optimal DG and SC placement and sizing as well as load curtailment. The new mathematical formulation of the minimization of the total system planning costs is described in (1):

$$\begin{aligned} \textit{Minimize} \qquad obj = {} & \frac{\sum_{i=1}^{B} C_{Inv_{DG}i} . P_{DG\,i}^{\max}}{A_{PB} * 8760} + \sum_{i=1}^{B} C_{O\&M_{DG}i} . P_{DG\,i} \\ & + \frac{\sum_{i=1}^{B} C_{Inv_{SC}i} . Q_{SC\,i}^{\max}}{A_{PB} * 8760} + \sum_{i=1}^{B} C_{O\&M_{SC}i} . Q_{SC\,i} \\ & + \sum_{i=1}^{G} C_{p\,i} . P_{G\,i} + loss * C_{p\,i} + ENS * C_{S\,ENS} \end{aligned} \tag{1}$$

This objective function aims to minimize: DG annualized investment, DG operation and maintenance costs, SC annualized investment, SC operation and maintenance costs, cost of purchasing power from other electric identities such as TRANSCOs (Transmission Company) connected to the DISCO distribution system, cost of energy losses, and cost of ENS (Energy Not Supply), respectively.

Before comparing investment costs and operating costs, it must apply a correction, because a currency unit to be paid in the future does not have the same value as available today. This time dependence of money is due to two quite different causes. The first is inflation, the well known and ever present erosion of the value of our currency. The second reflects the fact that money today can be invested to increase its value by profit or interest. Thus, the money that becomes available in the future is less desirable than the today money; its value must therefore be discounted. This is true even without inflation. Both inflation and discounting are characterized in terms of annual rates. It is convenient to express a series of payments that are irregular or variable as equal payments in regular intervals; in other words, one replaces nonuniform series by equivalent uniform or level series. This technique is referred to as levelizing. It is useful because regularity facilitates understanding and planning. To develop the formulas, it is possible to use the equation below [1], [2]:

$$A_{PB} = \left[\frac{(1+d)^{T_{PB}} - 1}{d(1+d)^{T_{PB}}} \right] \tag{2}$$

It is to be noted that loss appeared in the total power purchased from TRASCOs and DGs. Therefore, this term is added only to weight on its value in the object function. However, the system planner can omit the C_{loss} to the weight of the items that are equal. During the planning process a number of security, configuration and operating constraints must be satisfied. These constraints are discussed as follows [26], [27]:

Power balance equations: At each node in the network the power balance equations have to be satisfied.

$$\begin{aligned} \sum_{j \neq i} P_{ij} &= P_{G\,i} + P_{DG\,i} - P_i^d \\ \sum_{j \neq i} Q_{ij} &= Q_{G\,i} + Q_{SC\,i} - Q_i^d \end{aligned} \tag{3}$$

TRANSCOs limits: The TRANSCOs have a maximum and minimum capacity limit which is not feasible to dispatch due to technical or economic reasons. TRANSCOs limits are specified as upper and lower limits for the real and reactive power outputs.

Active and reactive power generation limits:

$$\begin{gathered} 0 \le P_{G\,i} \le P_{G\,i}^{\max} \\ Q_{G\,i}^{\min} \le Q_{G\,i} \le Q_{G\,i}^{\max} \end{gathered} \tag{4}$$

Distribution feeder load flow limit: Each feeder based on thermal considerations has a maximum power limit.

$$\left| S_{ij} \right| \le S_{ij}^{\max} \tag{5}$$

Bus voltage limit: Voltage limits refer to bus voltage to remain within an allowable narrow range of levels.

$$V_i^{\min} \le V_i \le V_i^{\max} \tag{6}$$

DG power capacity constraint: The active power generated from DG must be less than the maximum DG capacity

$$0 \le P_{DGi} \le P_{DGi}^{\max} \qquad \forall i = 1, \ldots, B \tag{7}$$

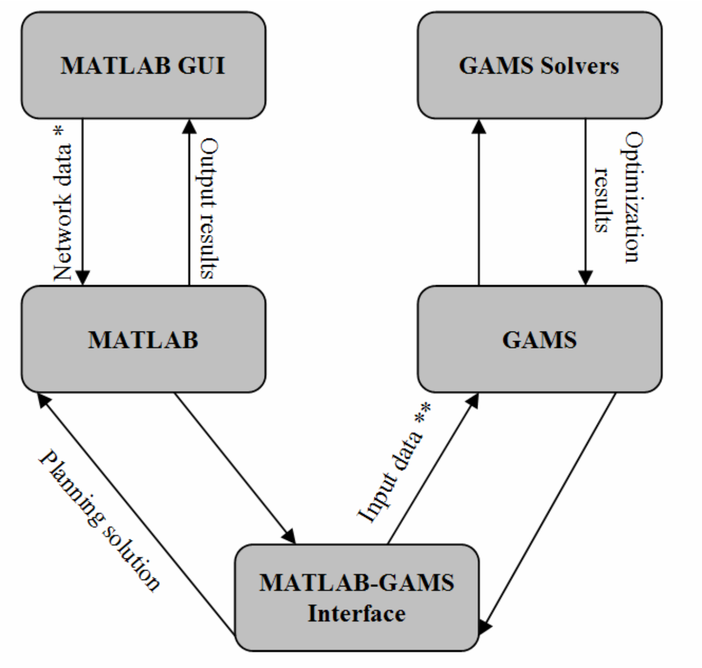
SC capacity constraint: The reactive power generated from SC must be less than its maximum capacity

$$0 \le Q_{SC\,i} \le Q_{SC\,i}^{\max} \qquad \forall i = 1,\ldots,B \tag{8}$$

Investment resource constraint: The proposed model introduces a new investment resources constraint for distribution system planning (Eq. 9). The DISCO often has to carry out investment planning decision-making while considering its financial constraints. This constraint imposes a limit on the DG and SC capacity the DISCO can invest in.

$$\sum_{i=1}^{B} C_{Inv_{DG}i} \cdot P_{DG\,i}^{\max} + \sum_{i=1}^{B} C_{Inv_{SC}i} \cdot Q_{SC\,i}^{\max} \le BCL \tag{9}$$

To find the best solution for the above mentioned distribution system planning problem quickly (below 1 second) a new software package is developed as interfacing between General Algebraic Modeling System (GAMS) [28], to solve various types of optimization problems such as LP, NLP, MILP, MINLP and Dynamic Non-Linear Programming (DNLP) and MATLAB, to use its visualization capabilities and easy data transfer (Fig. 1). The output of this option function is the optimal location and size of DG and SC in each investment payback time as well as load curtailed.



* Input data consist of: the network, electricity market and DG data
** In format of adjustable with GAMS

Fig. 1. Structure of the MATLAB-GAMS interface

b) Social welfare maximization

In the second stage social welfare is defined as the difference between total system costs before and after system development including DG and SC installation:

$$\text{Maximize} \qquad SW(T) = \sum_{t=T_{PB}}^{T} (Cost_B - Cost_A) \quad \forall T \tag{10}$$

Where $Cost_B$ and $Cost_A$ are the total costs of the system before and after system upgrading.
In determining the optimal payback time it is very important to know optimal DG life time (*T*). DG life time is dependent on the type of DG technology, its manufacturer, its operation condition, etc. The

minimization cost problem is viewed from the perspective of DISCOs owner, who chooses to place and size DG at the distribution system. The maximum social welfare problem is viewed from the perspective of DG owners who determine the optimal time to return the investment.

3. CASE STUDY

The distribution system under study in this paper is the standard IEEE 30-Bus system shown in Fig. 2 [29]. The total active and reactive load of this system is 283.4 MW and 126.2 MVar, respectively. There are two TRANSCOs connecting at buses-1 and 2 and also four SC at buses- 5, 8, 11 and 13. The system voltage is assumed to be 33 kV.

In this paper, Microturbine is chosen as the DG. The investment, fuel, operation and maintenance costs of this kind of DG are assumed to be 1 M$/MVA, 55 $/MWh and 5 $/MWh, respectively [15], [29]. However, the choice of each DG technology is limited to environment and system constraints. Each technology has a different cost. It is possible to study other types of DG technologies with the change of investment, operation and maintenance cost of DG. The candidate individual and total DG capacity for installation at each bus is assumed to be 1MW and 4MW, respectively. In this paper, it is assumed that electricity based market price is variable by 24-periods according to Fig. 3 as a typical curve. The discount rate is taken as 10%. The penalty of energy not supply is assumed to be 500 $/MW [30].

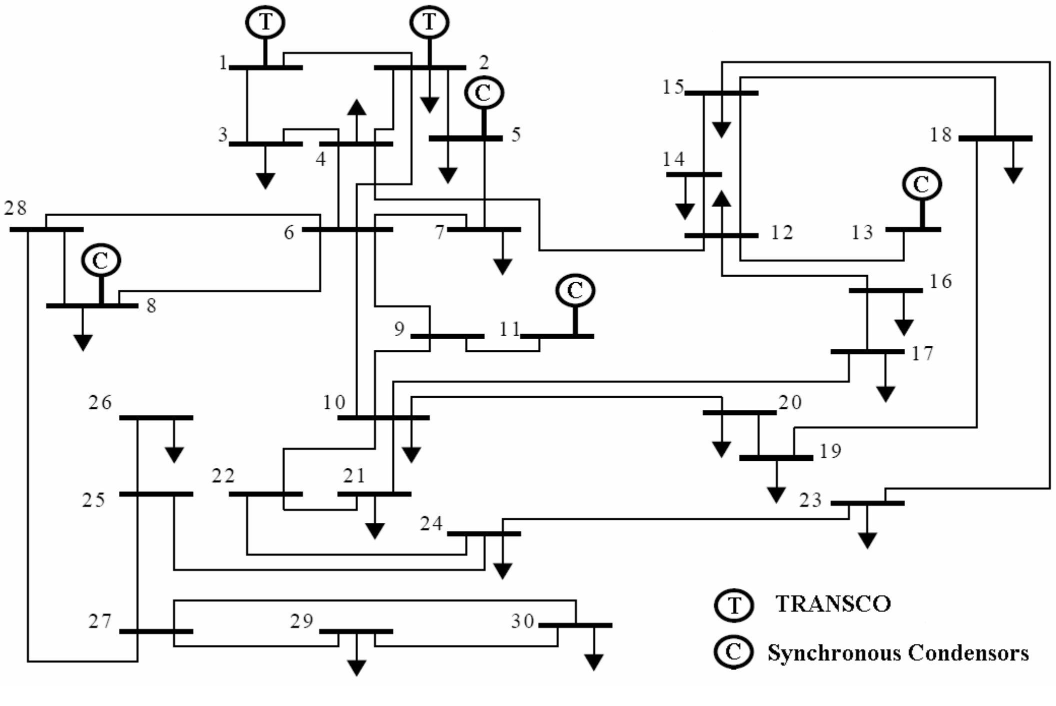


Fig. 2. IEEE 30-Bus system under study

4. SIMULATION RESULTS AND DISCUSSION

To study the effects of DG on the distribution system and the effects of condition of system on optimal placement and size of the DG, the three scenarios below have been discussed in this paper.

a) Scenario I

In this scenario the standard IEEE 30 bus test system is assumed as the case study. In this system, even after load growing, there is no congestion area or voltage problem; therefore this system can work without needing to add any other generation devices. In this situation, to supply the required additional power imposed by load growth, purchasing the required additional power from the TRANSCOs and/or installing new active and reactive power sources such as DG and SC in the distribution system is compared.

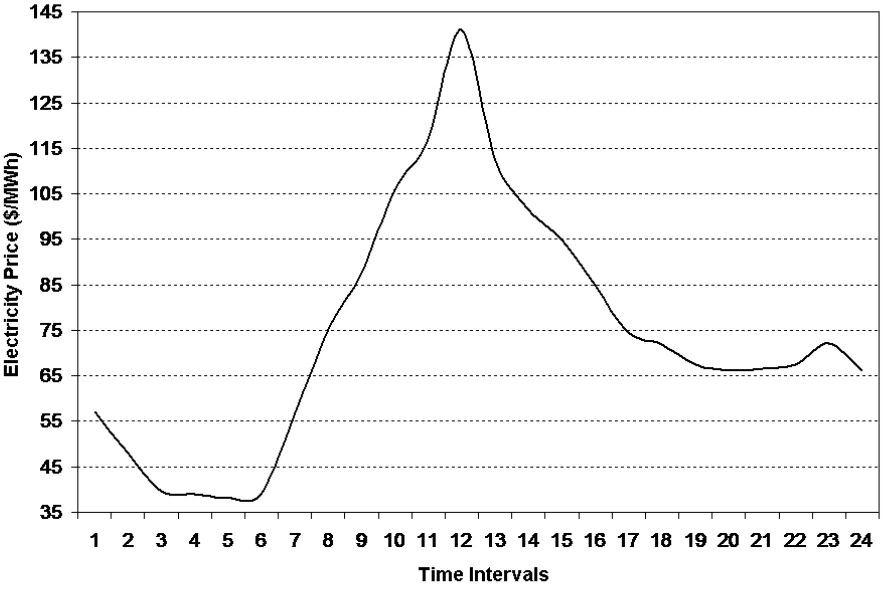


Fig. 3. Curve of electricity market price

1. Cost minimization: The results of simulation of scenario I are summarized in Table 1. It is to be noted, however, that although the capital, operation and maintenance costs of SC are less than the Microturbine costs, installation of SC is not suitable in any condition. In this table the effect of investment payback time on optimal DG placement and size is indicated. As it is shown in this table, in payback time less than 5 years, the installation of Microturbine is not economical.

Table 1. Optimal solution for distribution system planning in scenario I

	T_{PB} (yr)	Purchased active power from TRANSCOs (MW)	Purchased reactive power from TRANSCOs (MVar)	Purchased reactive power from condensers (MVar)	DG Capacity (MW) & Location	SC size (MVar) & location	Loss (MW)	Load shedding (%)	Invest. (M$)
Without DG installation	-	301.4	83	101.3	-	-	18.031	-	-
With Microturbine or SC installation	≥7	278.3	63.6	92.9	4 @ Bus# 5,19,30 3 @ Bus# 24 2 @ Bus# 7, 26 1 @ Bus# 29	-	14.936	-	20
	6	292.1	64.5	97.5	4 @ Bus# 30 3 @ Bus# 5 1 @ Bus# 26	-	16.675	-	8
	≤5	301.4	83	101.3	-	-	-	-	-

Figure 4 compares the electricity market price before and after Microturbine installation by payback time equal to seven. As declared in this figure, installation DG increases the electricity market price in cases where the price of market is lower than the DG price and decreases it when the market price is higher than the DG price. As a result, by supplying loads during peak load periods, where the cost of electricity is high, DG can best serve as a price hedging mechanism. According to its speed in shut up and shut down it is possible that the operator turns on the Microturbine only at the necessary time.

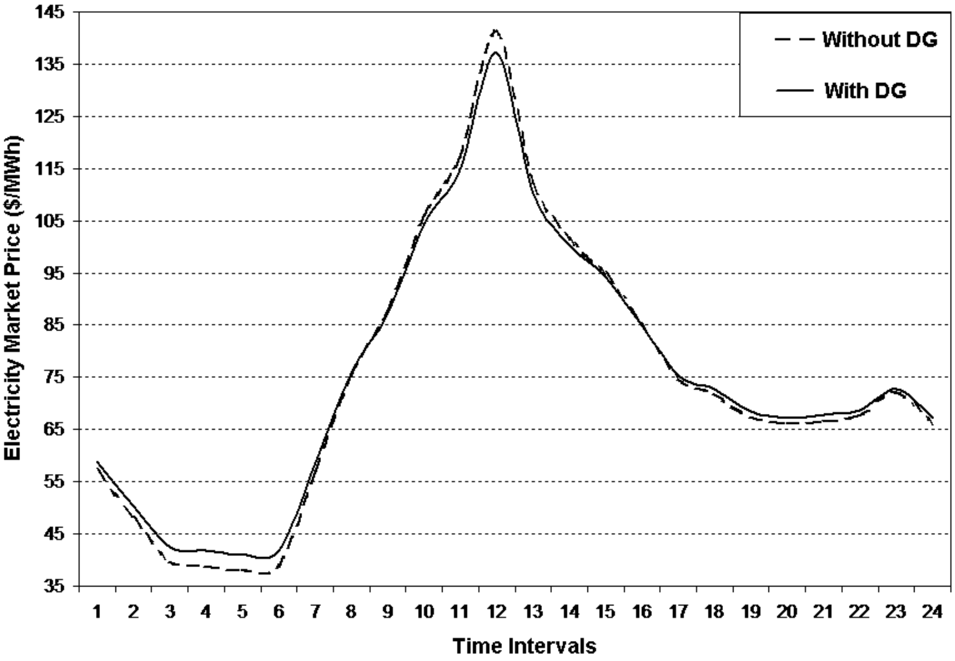


Fig. 4. Electricity market price before (solid line) and after (dash line) Microturbine installation

2. Social welfare: Microturbine life time (T) is dependent on its manufacturer, its operation condition, etc. In an other way, the DG life time has a huge effect on the decision to determine optimal investment payback time. Fig. 5 shows social welfare curves for different Microturbine life times between 10 and 20 years. Table 2 indicates optimal investment payback time in terms of different life times.

Table 2. Optimal payback time for Microturbine in scenario I

T (yr)	10, 11	12-14	15-20
T_{PB} (yr)	8	9	10

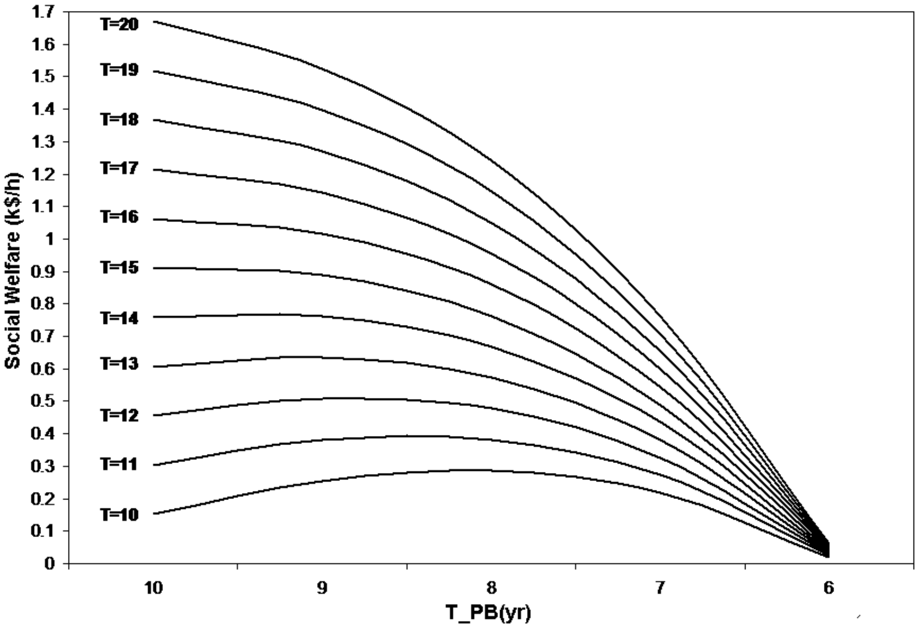


Fig. 5. Social welfare according to different payback time (T_{PB}) and Microturbine operating time (T)

b) Scenario II

In this scenario it is assumed that the 40MVar condenser at bus No. 8 is permanently out of service. In this situation the voltage of the system in some buses is not in its permissible limits. Therefore without DG installation, it is necessary to install voltage regulator devices to improve the system voltage. So, in this scenario the goal is to find the best combination of utilization of DG and SC (as an example of voltage regulator devices sufficient for this case study) to improve the system voltage as well as decrease the total system costs, losses and ENS.

1. Cost minimization: Table 3 shows the optimal DG and SC placement and their capacity. Two options have been considered in this case; with and without SC installation. The results of these options are different for $T_{PB}\leq 5$. Without DG or SC installation to converge power flow equations some loads should be interrupted. The optimal solution in this situation is to shed total load at bus no. 30.

2. Social Welfare: The results show that the optimal investment payback time is equal to seven years in different life times for Microturbine in the case of implementing DG and SC together.

Table 3. optimal solution for distribution system planning in scenario II

	T_{PB} (yr)	Purchased active power from TRANSCOs (MW)	Purchased reactive power from TRANSCOs (MVar)	Purchased reactive power from condensers (Mvar)	DG Capacity (MW) & Location	SC size (Mvar) & location	Loss (MW)	Load shedding (%)	Invest. (M$)
Without DG installation	-	289.8	61.1	73.4	-	-	16.996	100% @ #30	-
With Microturbine or SC installation	≥7	279	58.5	71.3	4 @Bus#5,19,24,30 2 @ Bus# 26 1 @ Bus# 7, 29	-	15.564	-	20
	6	285.8	60.7	73.2	4 @ Bus# 5, 30 2 @ Bus# 19, 26 1 @ Bus# 24, 29	-	16.446	-	14
	5	298.5	61.9	74.2	3 @ Bus# 30	3.5@ Bus #8 1 @ Bus #30	18.078	-	3.045
	≤5	288.2	61.2	73	4 @ Bus# 29, 30 3 @ Bus# 26 1 @ Bus# 24	-	16.833	-	12
	≤4	302	62	74.2	-	5@ Bus# 8, 1.5 @ Bus#30	18.598	-	0.065

c) Scenario III

In some cases, placing DG units in strategic locations can help delay the purchase of new transmission or distribution systems and equipment such as distribution lines and substations. In this scenario the effect of DG on the improvement of congestion of distribution feeders and deferring T&D investment is discussed. In such situation, it can serve the local load and effectively reduce the load as well as loss. It may be driven by competition to provide the best customer service for the most competitive price. Since T&D costs are borne directly by the DISCO, and the quality of delivery directly impacts customer perceptions of service, many DISCOs are continuing to plan carefully for T&D improvements, and some are considering DG alternatives.

1. Cost minimization: In this scenario it is assumed that the system feeders have a margin limit to transit the appearance power, and in addition, to omit SC at bus 8 (40Mvar). Without DG or SC installation to converge power flow equations some loads should be curtailed. Otherwise, the voltage profile in some buses (ex. Bus No. 12 and 30 in this case study) falls to its minimum permissible limit which in this state, the protection devices disconnect their related circuit breaker. The optimal solution in this situation is to shed total load at bus no. 12 and shed 70% load at bus no. 30. The target of this scenario is to determine the optimal placement and size of DG and SC with consideration of improvement of the power quality and feeder congestion, as well as to obtain the minimum costs. The results of the simulation with and without SC consideration are shown in Table 4. The results of these options are different for $T_{PB} \leq 4$.

Table 4. optimal solution for distribution system planning in scenario III

	T_{PB} (yr)	Purchased active power from TRANSCOs (MW)	Purchased reactive power from TRANSCOs (MVar)	Purchased reactive power from condensers (MVar)	DG Capacity (MW) & Location	SC size (MVar) & location	Loss (MW)	Load shedding (%)	Invest. (M$)
Without DG installation	-	281	60.4	88	-	-	16.216	100% @ # 12 70% @ # 30	-
With Microturbine or SC installation	≥6	279.2	59.1	70.6	4 @ Bus# 15, 3 3 @ Bus# 14,18,23 2 @ Bus# 19 1 @ Bus# 26	-	15.773	-	20
	5	280.4	59.7	70.9	4 @ Bus# 14,15,18 3 @ Bus# 23, 3 1 @ Bus# 19	-	15.993	-	19
	4	281.7	60.3	71.4	4 @ Bus# 12, 1 4 @ Bus# 15, 3 2 @ Bus# 13	-	16.305	-	18
		286.3	60.9	70.7	4 @ Bus#12,14,15 2 @ Bus# 13	1.5@ Bus # 26, 30	16.935	-	14
	≤3	282.8	60.6	71.7	4 @ Bus# 12,14,15 3 @ Bus# 30 1 @ Bus# 18, 23	-	16.405	-	17

2. Social Welfare: The results indicate that the best investment payback time in different life times is equal to six years. As a result, DG technologies can provide a stand-alone power option for areas where transmission and distribution infrastructure do not exist or is too expensive to build.

5. CONCLUSION

The aim of the distribution system planning is to assure that the growing load demand can be fulfilled technically and economically by optimal distribution system expansion. In this study it is assumed that the planner has three possible options; SC and DG installation or load shedding. In this paper, a new two-stage methodology is proposed to find the best solution between these options. The goal of this framework is to minimize cost and maximize social welfare. Optimal placement and size is identified as total cost minimization problem. For each investment payback time, there is an optimal location and size. Then the optimal payback time is obtained by social welfare maximization analysis. Different system conditions are simulated to illustrate the gross effect of DG on the distribution system as well as ability of the proposed methodology. This paper shows that, although DG may never supply the total distribution loads, it can be a powerful option, especially when the system voltage profile is unsuitable or constraints in transmission network prevent economic or the least expensive supply of energy reaching demand. However, penetration of DG at a particular location is influenced by technical as well as economic factors.

NOMENCLATURE

A_{PB}	Levelizing annual factor
B	total number of system buses possible to connect DG
BCL	DISCO Budget Capacity Limit ($)
$C_{Inv_{DG}i}$	DG investment cost ($/MW)
$C_{Inv_{SC}i}$	SC investment cost ($/MVar)
$C_{S\ ENS}$	Penalty of energy not supply ($/MW)
$C_{P\ i}$	Active power price of TRANSCO number *i* ($/MWh)
$C_{O\&M_{DG}i}$	DG operating and maintenance cost at bus *i* ($/MWh)
$C_{O\&M_{SC}i}$	SC operating and maintenance cost at bus *i* ($/MWh)
d	Discount rate
ENS	Energy Not Supply (MW)
G	total number of TRANSCOs connected to distribution system
$P_{DG\ i}$	DG generated active power at bus *i* (MW)
$P_{DG\ i}^{\max}$	Maximum DG capacity at bus i (MW)
$P_{G\ i}$	Active power dispatched from TRANSCO *i* (MW)
$P_{G\ i}^{\max}$	Maximum active power limit of TRANSCO *i* (MW)
P_i^d	Total active power demand at bus *i* (MW)
Q_i^d	Total reactive power demand at bus *i* (MVar)
$Q_{SC\ i}$	SC generated reactive power at bus *i* (MW)
$Q_{SC\ i}^{\max}$	Maximum SC capacity at bus i (MW)
$Q_{G\ i}$	Reactive power dispatched from TRANSCO *i* (MVar)
$Q_{G\ i}^{\max}$	Maximum reactive power limit of TRANSCO *i* (MVar)
$Q_{G\ i}^{\min}$	Minimum reactive power limit of TRANSCO *i* (MVar)
S_{ij}	Apparent power flow through line connected between *i,j* (MVA)
$S_{ij}^{\max}$	Maximum permissible line power flow capacity
T_{PB}	Investment payback time (year)
T	The predicted DG operating time (year)
V_i	Bus voltage at bus *i* (V)
$V_i^{\max}$	Maximum permissible voltage at bus *i* (V)
$V_i^{\min}$	Minimum permissible voltage at bus *i* (V)

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