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Composite Distributed Generation and Transmission Expansion Planning Considering Security

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***Abstract*—**During the recent past, due to the increase of electrical energy demand and governmental resources constraints in creating additional capacity in the generation, transmission, and distribution, privatization, and restructuring in electrical industry have been considered. So, in most of the countries, different parts of electrical industry like generation, transmission, and distribution have been separated in order to create competition. Considering these changes, environmental issues, energy growth, investment of private equity in energy generation units and difficulties of transmission lines expansion, distributed generation (DG) units have been used in power systems. Moreover, reduction in the need for transmission and distribution, the increase of reliability, improvement of power quality, and reduction of power loss have caused DG to be placed in power systems. On the other hand, considering low liquidity need, private investors tend to spend their money for DGs. In this project, the main goal is to offer an algorithm for planning and placing DGs in order to reduce the need for transmission and distribution network.

***Keywords*—**Planning, transmission, distributed generation, power security, power systems.

I. INTRODUCTION

RAPID growth in the consumer load in addition to electrical and thermal constraint could cause inadequacy in power systems. So, the main challenge is to provide the sufficient energy for the consumer with proper security, reliability, and safety through expanding transmission and generation [1]. Therefore, planning for the electric power sector encompasses generation, transmission, and distribution systems [2].

Transmission system plays a key role in providing secure electrical energy to the consumers [3]. In fact, the transmission systems largely determine the degree of the overall system economy and reliability levels. Planning for efficient and well-timed investments in electric transmission systems is an important open issue in power system planning [4].

Optimal planning of the transmission systems entails determining the right type, location, capacity, and timing of transmission expansions in order to deliver maximal social welfare over the planning period while maintaining adequate reliability levels. However, the Transmission Expansion Planning (TEP) problem is commonly simplified as a static optimization. In such a problem, setting the right configuration and timing for the investment is a major issue [1]-[5].

The investment in a power plant is mainly influenced by the environment such as power plant environment, e.g. water supply, dissipation conditions, and the cost of the land. In addition, the location also has a bearing on the entire system investment and operational cost. DG is typically defined as small generators, typically less than 100-MW, that are connected to utility distribution systems. Recent technology advances related to micro-turbines and fuel cells have created the possibility of competitive electricity generation with DG units as small as 1 kW. DG is a good option for producing new capacity, considering economic, technical, and environmental matters [1]. In this case, micro-turbine is used as DG. Micro-turbines are a relatively new DG technology being used for stationary energy generation applications. They are a type of combustion turbine that produces both heat and electricity on a relatively small scale. Micro-turbines offer several potential advantages compared to other technologies for small-scale power generation, including: a small number of moving parts, compact size, lightweight, greater efficiency, lower emissions, lower electricity costs, and opportunities to utilize waste fuels. Waste heat recovery can also be used with these systems to achieve efficiencies greater than 80% [5].

Because of their small size, relatively low capital costs, expected low operations and maintenance costs, and automatic electronic control, micro-turbines are expected to capture a significant share of the DG market. In addition, micro-turbines offer an efficient and clean solution to direct mechanical drive markets such as compression and air-conditioning [5]-[6].

One of the primary advantages of DG is that it can be located close to the load that it serves, eliminating much of the need for transmission and distribution (T&D) infrastructure. DG has always been an attractive alternative for rural areas where T&D costs are high [4], and DG is quickly becoming an attractive option for more densely populated regions due to the uncertainties associated with industry restructuring and difficulties in permitting discourage new T&D investments [2].

Because of the uncertainties in generation and load growth, a number of scenarios are considered. Although power plant planning is done for years later, the construction and installation of the power plants might be delayed. So, each scenario consists of the probabilities of power plant construction and installation and load growth for the coming years [7].

So, considering all above, using DG in TEP will cause in the transmission expansion deferral and the increase in welfare. In this paper, we will present a heuristic approach to solve TEP considering DG. This goal will be achieved by introduction of the candidate transmission lines to be expanded and possible substations which DG units could be

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II. PROBLEM DESCRIPTION

The goal of the integrated transmission, substation, and DG expansion planning process is to identify the combination of expansion projects that satisfy load growth constraints without violating any system constraints such equipment overloading. The problem has been solved for couple of years in a specified planning horizon. While solving, the below points are considered:

- In general, the composite expansion planning is Mixed Integer Non-Linear Programming problem; however in this paper, the problem is solved with heuristic approach [1]- [8].
- The input of the problem is the existing network data including transmission lines, loads, and power plant parameters [9].
- The planning problem is a static type. In the other words, the planning is done at the beginning of the planning horizon analysing all periods at the beginning. In this case, the periods are seasonal as shown in Fig. 1. Moreover, the forecasted load for each season is known [10].
- Load duration curves represent the operating conditions of power systems over a year which is divided into four seasons. They are obtained from hourly data of demand over a period of time. For each bus, the load duration curve is available [8].
- At each bus, a number of DGs can be installed. The maximum number of DGs in a bus is constrained by the available space at each substation [9].
- The existing transmission line cannot be removed and will be connected. The generation of each plant will be calculated by Optimal Power flow. Any line between two buses can be double, triple, and so on [11].
- Future power plants construction and installation will be considered in this optimization [12].
- The cost of each scenario is calculated, then the probability of each scenario is multiplied by its probability [10].
- A specific amount of reserve power is considered for the power plants. So, the optimal power flow is run considering the reserve.

III. PROBLEM FORMULATION

This problem is the optimization one to be solved by Genetic Algorithm (GA). A GA is a method for solving both constrained and unconstrained optimization problems based on a natural selection process that mimics biological evolution. The algorithm repeatedly modifies a population of individual solutions. At each step, the GA randomly selects individuals from the current population and uses them as parents to produce the children for the next generation. Over successive generations, the population evolves toward an optimal solution. GA Generates a population of points at each iteration. The best point in the population approaches an optimal solution. The algorithm selects the next population by computation which uses random number generators [13].

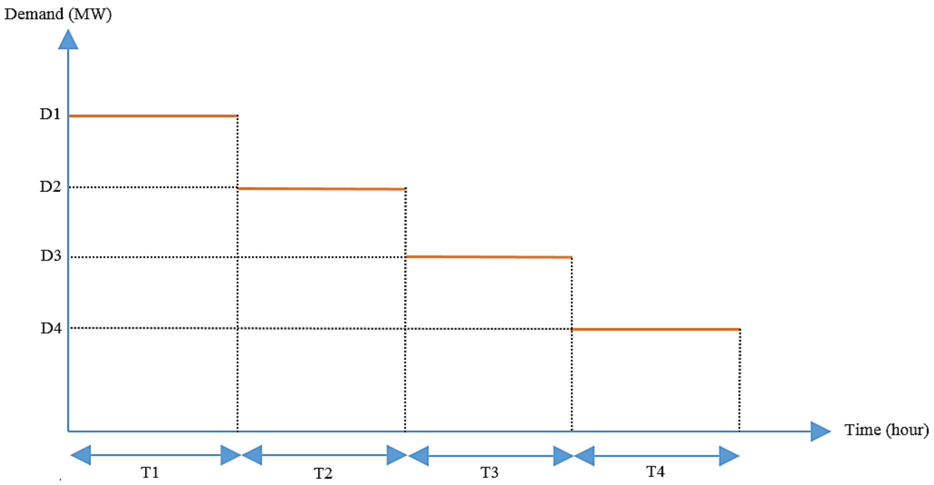

Fig. 1 Seasonal Load Duration Curve

The formulation of composite transmission and DG expansion considering uncertainties is described in this section. In this problem by combining Generation Expansion with Transmission Expansion, the main goal is to find out whether to invest the money and install new DG, new transmission line or a combination of both. The voltage and generation of all of the power plants should be calculation via Optimal power flow to have the maximum welfare and minimum cost. The Objective function terms will be discussed in the following subsections.

A. Objective Function

A specific problem formulation is as follows:

- The Objective function is the sum of Generation and Transmission expansion costs. The cost of the year (T) is converted to the Net Present Value (NPV). For this calculation, the interest rate is introduced. At last, the probability of each scenario will be considered in the final

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objective function. So the Objective function is:

$$\text{Objective function}= \sum_{s=1}^{p} p_s * \sum_{t=1}^{T} NPV_t \quad (1)$$

$$NPV_t = \frac{1}{(1+r_{in})^t}\, Cost_t \quad (2)$$

$$Cost_t = \sum_{i=1}^{n}\sum_{j=i+1}^{n} LC_{ijt} + \sum_{g=1}^{G} GC_g + \sum_{m=1}^{M}(IDGC_m + GDGC_m) \quad (3)$$

B. Constraints

The constraints to be considered in this case are as below:

- Network capacity constraints: The current and power flow of the transmission lines should not exceed the maximum value. This constraint mainly is set because of thermal problems.
- Network security constraints: The voltage of transmission lines and buses should not be more than a consistent value. A security index is set to determine and compare the security of bus (i) is as below:

$$SI_i = \frac{V_i}{V_{min}} + \frac{V_{max}}{V_i}$$

- DG placement area constraints: DGs are installed at substations and due to the limited area of substations, DG placement area constraints should be considered.
- Network feasibility constraints: The Optimal power flow of the suggested network design should be feasible.

Input Data

The following data are the input for the developed Matlab program to calculate the objective function:

- Existing network configuration and parameters: The line parameters including reactance, resistance, susceptance and Maximum power flow.
- Forecasted system seasonal demand: The predicted load curve for all of the four season should be available for the process.
- New DG costs: The investment and generation costs of the DGs must be available.
- New transmission routes, line parameters, and costs: The candidate transmission expansion lines between two buses are needed. Also the line types, the number of circuits, investment and installation cost are the inputs.
- Feasible DG locations and Area constraints: The substations have limited space and area for micro-turbine installation. So, available area is an input for the problem.

IV. SOLUTION ALGORITHM

The optimization problem formed by equation (1-3) and the constraints defined in Section III, is a Mixed Integer Non-Linear programming, which it would take a lot of time to solve mathematically for large scale systems. So in this problem, a heuristic approach is taken called GA. This optimization problem can be divided into two phases as shown in Fig. 2.

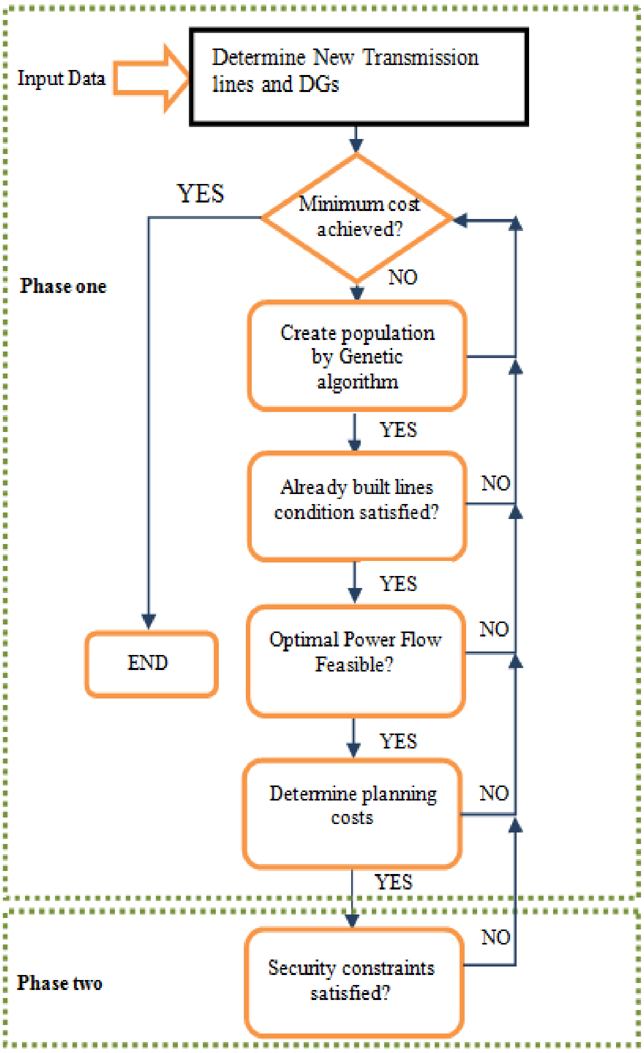

Fig. 2 Solution flow chart

A. Phase One

In the first phase, at the beginning, the input data including generation, load, network parameters, new DGs and transmission lines are given. Then, the GA begins to generate random populations. The upper and lower bounds of the populations are set. The generated populations can be divided into two parts. The first part is the number of transmission lines between two buses. For example, the number 0 shows that there is no connection between the buses, 1 is a single circuit, 2 is a double circuit, and so on. The lower bounds are the number of existing circuits before the planning is executed. The upper bounds are set due to the constraints. After the primary settings, the GA is run. Each time, the algorithm suggests a number of transmission lines and DGs.

Then, the suggested plan is checked for the feasibility by the optimal power flow. If the plan is feasible, the next step is to calculate the overall costs of the plan.

B. Phase Two

After the cost calculation, security constraints are checked. Any suggested design will be checked with "N-1 congestion" method. Each time, one of transmission lines and DGs will be out of order to check for any blackouts. If the suggested plan does not satisfy the loads, then the other design is checked until the plan with minimum cost and preferable security is achieved.

TABLE I
SEASONAL LOAD

Bus	Season1	Season2	Season3	Season4
1	80	120	130	90
2	240	260	250	200
3	40	60	60	60
4	160	200	180	160
5	240	260	260	210
6	0	0	0	0

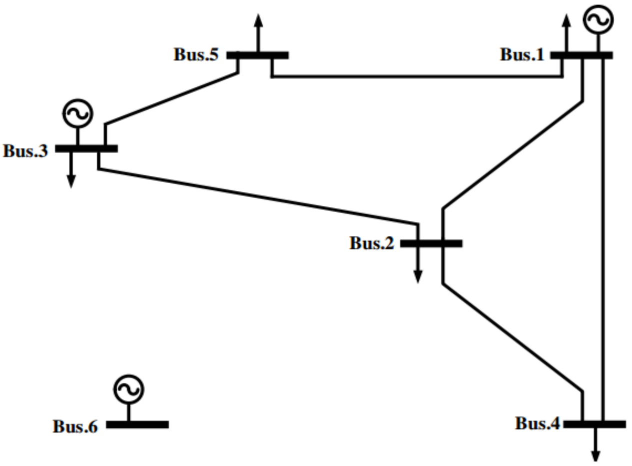

Fig. 3 Garver network

V. CASE STUDY AND NUMERICAL EXAMPLE

Following, a detailed numerical example shown in Fig. 3 (Garver network) built in an actual setting, demonstrates the importance of TEP considering DG. Let us consider a network which will be considered to be analyzed for five years. It is known with certainty that the load will be constant over five years. The seasonal load of each bus is also known. So, the power flow will be run four times. Table I is the seasonal load of the network. The duration of each season is considered to 8760 hours. Table II is the existing transmission lines parameters of the network including reactance, line flow limits, investment costs. Table III shows the generation costs of the power plants in the form below. In order to calculate the operation, cost in a year for four seasons, it is necessary to calculate the optimal power flow of the network. Table IV shows the investment operational cost of DGs. DG capacity is 20 MW per module. It is assumed that when DG units are online, the generated power is constant at maximum capacity.

First, the upper and lower bounds of the GA are set. The increase rate of power plant capacity and load at each bus is 5 and 7 percent, respectively. The interest rate is 10 percent. So the optimization is run by DC Optimal power flow. Then, the security check is run on the optimized plan (X). The upper bound of the problem is the one shown below.

$$UB = X + \text{ones}\ (1,21)$$

This means that the upper bound network configuration is a network that at each connection between two buses, there is an extra line just for security reasons although this plan costs more than the optimized one. So, the optimum network which has the desired security is achieved via GA. The optimization is done with both DCOPF and ACOPF. The result has a slight difference.

The result is shown in Tables V and VI.

TABLE II
EXISTING AND CANDIDATE TRANSMISSION NETWORK PARAMETERS

From	To	X (pu)	Line flow limits(MW)	ICT(M$)	Already built
1	2	0.40	100	40	1
1	3	0.38	100	38	0
1	4	0.60	80	60	1
1	5	0.20	100	20	1
1	6	0.68	70	68	0
2	3	0.20	100	20	1
2	4	0.40	100	40	1
2	5	0.31	100	31	0
2	6	0.30	100	30	0
3	4	0.59	82	59	0
3	5	0.20	100	20	1
3	6	0.48	100	48	0
4	5	0.63	75	63	0
4	6	0.30	100	30	0
5	6	0.61	78	61	0

TABLE III
GENERATION COSTS OF THE POWER PLANTS

Node	Generation			
	Name	A_i	B_i	Capacity(MW)
1	G1.1	0.002	10	150
2	-	-	-	-
3	G3.1	0.004	20	120
	G3.2	0.006	22	120
	G3.3	0.006	25	120
4	-	-	-	-
5	-	-	-	-
6	G6.1	0.002	8	100
	G6.2	0.002	12	100
	G6.3	0.004	15	100
	G6.4	0.004	17	100
	G6.5	0.004	19	100
	G6.6	0.006	21	100

TABLE IV
INVESTMENT COST OF DGS

Investment cost	**700000$/MW**
Operation cost	10$/MWh
Module capacity	20MW

VI. CONCLUSION

For the Garver system, the problem of composite DG and TEP considering security was addressed. Additionally, improved levels of adaptability, voltages, and security have been achieved. These benefits are reflected in the objective function.

TABLE V
OPTIMIZED NETWORK WITHOUT SECURITY

Transmission line	DCOPF	ACOPF
1-2	1	1
1-3	0	0
1-4	1	1
1-5	1	1
1-6	0	0
2-3	1	1
2-4	1	1
2-5	0	0
2-6	2	2
3-4	0	0
3-5	2	2
3-6	0	0
4-5	0	0
4-6	0	0
5-6	0	0
DG1	2	1
DG2	0	0
DG3	0	0
DG4	1	2
DG5	1	1
DG6	0	0

TABLE VI
OPTIMIZED NETWORK WITH SECURITY

Transmission line	DCOPF	ACOPF
1-2	1	1
1-3	0	0
1-4	1	1
1-5	1	1
1-6	0	0
2-3	1	1
2-4	1	1
2-5	0	0
2-6	2	2
3-4	0	0
3-5	2	3
3-6	0	0
4-5	0	0
4-6	1	1
5-6	0	0
DG1	3	1
DG2	1	0
DG3	0	0
DG4	2	3
DG5	2	1
DG6	0	0

The objective was to minimize the overall cost of the system by installing DG at the buses and determining the new transmission element additions. The problem was formulated as a mixed integer linear and non-linear for DCOPF and ACOPF respectively solved by a heuristic approach called GA. The most important benefits of the proposed solution are the possibility of considering the constrains of power plants, the reliability constraints of power plants and transmission network, determination of the exact location of micro-turbine DGs considering demand growth.

The proposed strategy can help governments to gain information about the preferred DG technologies for each region in order to keep moving towards sustainable development. From the case study, it can be seen that the proposed method could be a useful tool for the composite expansion planning for power systems.

NOMENCLATURE

p	Maximum number of scenarios
s	Scenario number
p_s	Scenario probability
NPV	Net Present Value
T	Period time
t	Year number
r_{in}	Interest rate
$COST_t$	Cost of transmission and DG planning in year t
LC_{ijt}	Transmission line cost from bus i to j at year t
n	Maximum number of buses
GC_g	Generation cost of power plant g
G	Maximum number of power plants
g	Power plant number
$IDGC_m$	Investment cost of mth DG
m	Number of DG
M	Maximum number of DG
$GDGC_m$	Generation cost of mth DG
V_{min}	Minimum allowed voltage
V_{max}	Maximum allowed voltage
V_i	Voltage of bus i

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