OPTIMAL OPERATION OF DISTRIBUTION NETWORK CONSIDERING RENEWABLE ENERGY SOURCES BY BINARY PARTICLE SWARM OPTIMIZATION AND FUZZY THEORY

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ABSTRACT

Today, the development of telecommunications infrastructure has led to rapid exchange of data between the distribution network components and the control center. On the other hand, renewable energy sources (RES) are increasing due to deregulation and restructuring in power systems, global warming and reduction of fossil fuels .These sources are connected to the distribution network therefore behavior of these networks will change. One of the most important problems is the optimal operation of the distribution network including renewable energy sources. Optimal operation of distribution network is a mixed integer, nonlinear and multi-objective problem. Therefore in this paper, binary particle swarm optimization and fuzzy set theory are used for solved the problem. Finally, a practical distribution test system is used to investigate the feasibility and effectiveness of the proposed method.

INTRODUCTION

In recent year, a growing trend for finding new environmentally friendly replaceable sources of energy have been made to reduce the harmful effects of the conventional energy sources; i.e. to find alternative nontraditional/renewable energies. Low emission, high efficiency, compatibility with other modular subsystems and suitable power quality and reliability are of benefits of RES [1]. Connecting RES to distribution systems may change the direction of power flow which is not considered in conventional control approaches. There are many literatures investigating the effect of Distributed Generation (DG) resources on distribution systems. The authors of [2] suggest the optimal voltage control of distribution systems in the presence of DGs and other devices. In this reference, losses and voltage deviation are considered as objective functions and the optimization problem is solved using weighted coefficients singe objectively. In [3] optimal control of DGs and capacitors are described using hybrid discrete particle swarm algorithm. Reference [4] addresses voltage and reactive power optimization by means of modified genetic algorithm. In this reference, losses and voltage deviation are considered as objective functions too and the single objective problem is solved. In the foretelling literatures not only is the optimization problem solved singly objective but also other operational objectives such as active power generation costs and emission are not considered. In this paper, several installed devices in real distribution systems such as RES, voltage regulator (VR), On Load Tap Changer (OLTC), Static Var Compensator (SVC), and shunt capacitors (SHC) are modelled. Moreover, all operational objectives are considered. Furthermore, the distribution system operation problems are solved multi-objectively using fuzzy theory and max, min operators.

RENEWABLE ENERGY SOURCES MODELLING

Distributed generations can utilize the traditional energy sources such as oil and coal or RES such as wind, solar and fuel cell and use rotating generators or converters to transfer energy to power grids. In this paper, wind turbine and solar photovoltaic (PV) are considered as RES. The performance of the wind turbines is based on the conversion of the kinetic energy of wind into electricity. Solar photovoltaics (PVs) are arrays of cells containing a material which converts solar radiation into direct current (DC) electricity. There are different models of RES according to their operation technology and connection to the grid. In this paper the RES is modelled as constant active and reactive load with simultaneous three-phase control.[5]

SVC MODELLING

SVC is a reactive power compensation device which is formed by conventional compensators (e.g. capacitor and reactor) and controlled by thyristor. SVC has the capability of reactive power control and generation rapidly. As is shown in Fig. 1 this device is modelled as reactive power source for simplicity.

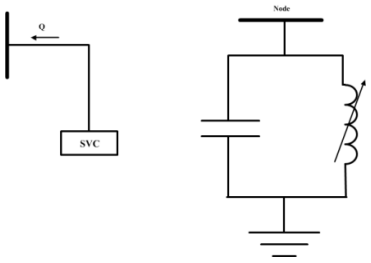


Fig. 1 SVC model and it's equivalent circuit [2].

MATHEMATICAL MODELLING OF PROBLEM

Clearly, optimal operation of distribution systems is an optimization problem with discrete and continuous variables. In this paper, minimization of voltage deviation of buses, losses, emission and cost of active power generated by grid and RES are considered as objective functions which are formulated in equation (1)-(4), respectively.

$$f_1(X) = \frac{\sum_{t=1}^{24}\sum_{i=1}^{N_{bus}} \frac{\left|V_i^{ref} - V_i\right|}{V_i^{ref}}}{24 \times N_{bus}} \quad (1)$$

$$f_2(X) = \sum_{t=1}^{24}\sum_{i=1}^{N_{bra}} R_i \times \left|I_i\right|^2 \quad (2)$$

$$f_3(X) = \sum_{t=1}^{24} E_{grid} \times P_{sub} + \sum_{t=1}^{24} E_{PV} \times P_{PV} + \sum_{t=1}^{24} E_{WF} \times P_{WF} \quad (3)$$

$$E_{grid} = (CO_2 + SO_2 + NO_X)^{lb/Mwh} = (2031 + 7.9 + 5.06)^{lb/Mwh}$$

$$E_{PV} = E_{WF} = 0$$

$$f_4(X) = \sum_{t=1}^{24} Price_h \times P_{sub} + \sum_{t=1}^{24} C_{PV} \times P_{PV} + \sum_{t=1}^{24} C_{WF} \times P_{WF} \quad (4)$$

$$X = \left[\overline{T_{OLTC}}, \overline{T_{VR}}, \overline{C_c}, \overline{P_{PV}}, \overline{P_{WF}}, \overline{Q_{svc}}\right]_{1\times N}$$

$\overline{T_{OLTC}}$: Tap situation vector of OLTC

$\overline{T_{VR}}$: Tap situation vector of VR

$\overline{C_c}$: Capacitor situation vector

$\overline{P_{PV}}$: Active power output vector of PV

$\overline{P_{WF}}$:Active power output vector of Wind Farm

$\overline{Q_{svc}}$: Reactive power output vector of SVC

Where V_i^{ref} is reference voltage of *i*th bus; V_i is the voltage of *i*th bus; $Price_h$ is hourly cost of energy; P_{sub} is power generated by grid; E_{grid} is the emission generated by grid; E_{PV} and E_{WF} are emission generated by RES which are assumed as zero in this paper; R_i is resistance of *i*th branch; I_i is the current of *i*th branch; N_{bra} is the number of branches; N is the number of problem variables; C_{PV} and C_{WF} are the cost of power generation via RES which include operation and maintenance cost of these sources. Detailed calculations of these costs are reported in [6].

CONSTRAINTS

The constraints of problem are described in equations (5)-(12).

$$V_i^{\min} < V_i < V_i^{\max} \quad (5)$$

$$t_{\min} < T < t_{\max} \quad (6)$$

$$Q_{svc}^{\min} < Q_{svc} < Q_{svc}^{\max} \quad (7)$$

$$P_{PV}^{\min} < P_{PV} < P_{PV}^{\max} \quad (8)$$

$$P_{WF}^{\min} < P_{WF} < P_{WF}^{\max} \quad (9)$$

$$\left|I_{ij}^{line}\right| \le (I_{ij}^{line})^{\max} \quad (10)$$

$$PF_{\min} \le PF \le PF_{\max} \quad (11)$$

$$NS \le NS^{\max} \quad (12)$$

Equation (5) and (6) ensure buses voltages and taps locate in the desired range, respectively. Equation (7) describes the constraint of injection or absorption of reactive power of SVC. While equation (8) and (9) represent the constraint of active power generation of RES. Equation (10) is related to thermal constraint of lines and equation (11) describes the power factor constraint of main substation. Moreover, with respect to the effect of switching on devices aging, the maximum number of switching is also considered which is represented in equation (12).

SOLVING THE PROBLEM

As is stated hitherto, optimal operation of distribution network is a non-linear mixed-integer programming. Mathematical techniques are not suitable to solve this problem, since they are model-based and the precise model of system is needed for derivation.Whereas, Particle Swarm Optimization (PSO) is a population-based and free derivative method and Also it has no evolution operators such as crossover and mutation (these operators are time consumer).Therefore, to solve the problem in this paper, PSO is used. PSO is a Meta

heuristic algorithm developed by "Kennedy" and "Eberhart" that simulates the social behaviours of bird flocking or fish schooling and the methods by which they find roosting places, foods sources or other suitable habitat.[7]. In this paper, binary form of PSO is used and decoded is used to separate discrete and continuous variables.

FUZZY MODELLING OF OBJECTIVE FUNCTIONS:

As is stated hitherto, four objective functions for optimal operation of distribution systems in the presence of distributed generation resources are considered in this paper. These objective functions have different units; therefore, according to Fig.2 a fuzzy membership function is defined for every objective function [8].

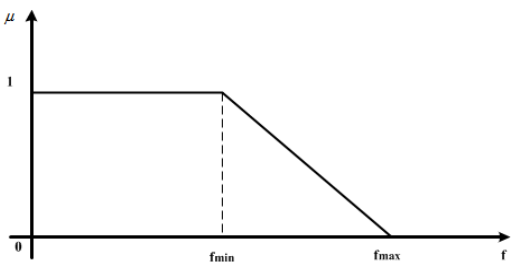


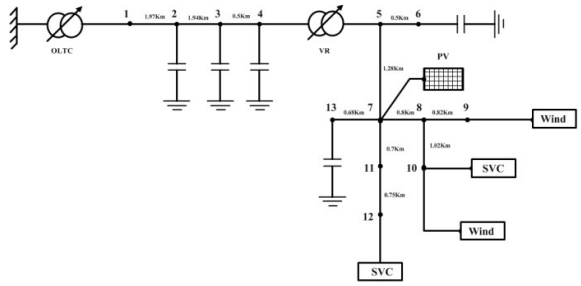
Fig. 2 Membership Function

Where f_{min} and f_{max} are the minimum and maximum values of any objective, respectively; this is led to all objective functions become non-dimensional and lie between (0, 1). Finally, the optimal answer is selected according to equation (13) using max, min operators.

$$\text{Best Solution}(X) = \max\left(\min\left[\mu_{f1}\ \mu_{f2}\ \mu_{f3}\ \mu_{f4}\right]\right) \quad (13)$$

SIMULATION

An actual distribution system which is part of Tehran distribution system is used as test system in this paper. One line diagram of this system in the presence of RES and other devices is shown in Fig.3. Impedance of over head lines is 0.362+j0.348 (Ohm/Km). Furthermore, hourly load and energy cost variations are illustrated in Fig.4 and Fig.5, respectively. In this system, the rated reactive powers of capacitors are 200kVAr and they can transit between ON and OFF situations. The tap of OLTC and VR are increased from 0.95 to 1.05 with 0.01 tap step. The maximum allowable number of switching of the OLTC and the VR is 30 in a day. Therefore, in this simulation, maximum number of switching of the OLTC and the VR not considered. The maximum number of switching of the SHC is 5 in a day. This system have two 1MW-wind plants and a 500kW-solar plant which are installed at bus 9, bus 10 and bus 7, respectively. Moreover, two 400kVAr- SVCs are installed at bus 10 and bus 12.



Bus	1	2	3	4	5	6	7	8	9	10	11	12	13
P(Kw)	0	890	628	1112	636	474	1342	920	766	662	690	1292	1124
Q(Kvar)	0	757	534	945	541	403	1141	782	651	563	587	1098	955

Fig. 3 Distribution Test System

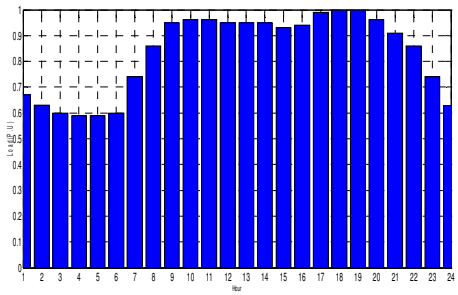


Fig.4 Hourly Load Variations

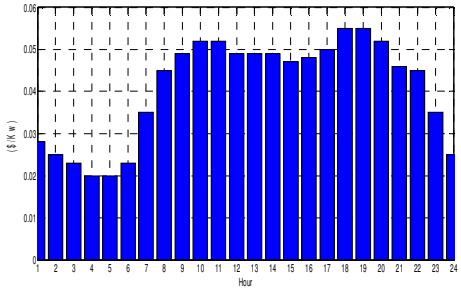


Fig.5 Hourly Energy Cost Variations

SIMULATION RESULTS

In this paper, three scenarios are defined. In the first scenario, no control devices are considered. In the second scenario, all devices of system are taken into account except RES. Finally, in the third scenario, all devices of system are considered. Table I lists the values of objective function in all scenarios. It can be perceived from this table, all operational objectives will be enhanced, provided that RES are connected to system and can be controlled. Table II shows the number of switching events in the presence and absence of RES. As can be seen from this table, the number of switching events which is led to device aging can be reduced by RES control. Hourly output values of RES are shown in Fig.6; As can be seen RES generate around their rated

capacities most of the times; hence, RES play major roles in the optimal operation of distribution systems. Moreover, to show the efficiency of Binary PSO algorithm in problem solution, the obtained results in scenario3 are compared with results obtained from genetic algorithm which is of the strongest optimization algorithms (Table III).

Table I. values of objective function

Objective function	Senario1	Senario2	Senario3
Cost($)	9.88E+03	9.67E+03	7.59E+03
Loss(kw)	18.9833	14.2411	7.45
Deviation (p.u)	0.0704	0.028	0.018
Emission(lb)	4.69E+05	4.59E+05	3.37E+05

Table II. Number of switching with and without RES

capacitor	Without RES	With RES
C2	10	4
C3	13	5
C4	9	5
C6	11	5
C13	6	3

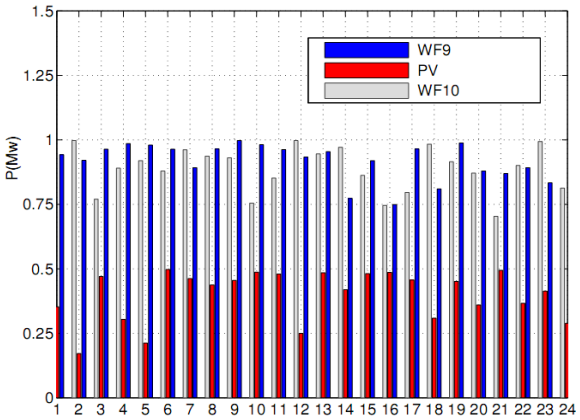


Fig.6 Output of RES On a Day

Table III. Comparison between PSO and GA

Objective function	PSO	GA
Cost	7.59E+03	7.61E+03
Loss	7450	7462
Deviation	0.018	0.023
Emission	3.37E+05	3.38E+05

CONCLUSIONS

Increasing development of using renewable energies is led to reviewing of distribution system planning. In this paper, the effect of renewable resources on operation of distribution systems is investigated. The results show these resources play major roles in enhancing operational objectives such as minimization of costs, losses, voltage deviation and emission. To solve optimal operation problem in this paper, binary PSO method is suggested; moreover, the efficiency of this method to solve problem is validated using a real practical system. Furthermore, optimal operation of distribution system is a multi objective problem which is solved in this paper using fuzzy theory and max, min operators.

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