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Combined Economic and Emission Dispatch Using Multiobjective Particle Swarm Optimization with SVC Installation

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Abstract

This paper presents an effective method for optimal power flow (OPF) of combined economic and emission dispatch by employing multiobjective particle swarm optimization for a standard IEEE 30 bus system. The harmful ecological effects caused due to emission of particulate and gaseous pollutants from fossil fuel power plants, can be reduced by proper load allocation among the various generating units. Particle Swarm Optimization is employed for minimization of total cost which includes economic dispatch and emission component. For improved performance of the power system Static Var Compensator (SVC) is installed in the IEEE 30 bus system. Results for optimization of total cost with and without SVC installation by considering the limits on generator real and reactive power outputs, bus voltages and transformer tapings have been obtained.

Keywords

Particle Swarm Optimization (PSO), Optimal Power Flow (OPF), FACTS, Emission Control, Power System.

1. Introduction

The economic dispatch difficulty has taken an appropriate twist as the public began to worry about environmental situations. The absolute minimum cost is not any more the only condition to be satisfied in the electric power generation and dispatching difficulties. On the other hand, considering only the operation of minimum environmental impact is not practical because of the high production cost of the system. Conversely, to operate the generating system with the lesser production cost will result in higher emission. As a result, economic dispatch, emission dispatch or combined economic and emission dispatch is in some way selected separately or combined together.To determine the suitable solution to this difficulty, an excellent power management approach is set.Various optimization methods like lambda iteration, linear programming, non-linear programming, quadratic programming, interior point technique or even intelligent search techniques (e.g. Genetic Algorithm (GA), Evolutionary Programming (EP), Particle Swarm Optimization (PSO), etc.) are used to overcome several economic dispatch difficulties and also the unit commitment difficulties.

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling. Particle swarm optimization (PSO) is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. To obtain economic load dispatch of a power system, PSO is included in Optimal Power Flow (OPF) technique. OPF seeks to optimize a certain objective, subject to the network power flow constraints and system and equipment operating limits [2-4].

In present work, Section 2 deals with general problem formulation for Optimization problem and also combining of economic and emission dispatch is explained. In Section 3, Particle Swarm Optimization and its algorithm on application to OPF is discussed in detail. Section 4 deals with Static Var Compensator installation in power system and finally in Section 5 the results obtained and comparison graphs for IEEE 30 bus system without and with SVC are presented.

2. Problem Formulation

The standard OPF problem can be formulated as a constrained optimization problem mathematically as follows:

$$\begin{aligned} &\text{minimize } f(x) \\ &\text{subjected to } g(x) = 0 \qquad (1) \\ &h(x) \leq 0 \end{aligned}$$

where $f(x)$ is the objective function, $g(x)$ represents the equality constraints, $h(x)$ represents the inequality constraints and x is the vector of the

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control variables such as generator real power Pg, generator voltages Vg, transformer tap setting T, and reactive generations of VAR sources Qc. Therefore, x can be expressed as

$$x^T = [Pg_1, Pg_2, \ldots \quad Pg_{ng}, Vg_1, Vg_2, \ldots \quad Vg_{ng}, T_1, T_2, \ldots. \quad T_{nt}, Qc_1, Qc_2, \ldots \quad Qc_{nc}] \quad (2)$$

where ng is the number of generator buses, nt is the number of transformer branches and nc is the number of shunt compensators.

The essence of the optimal power flow problem resides in reducing the objective function and simultaneously satisfying the load flow equations (equality constraints) without violating the inequality constraints.

Objective Function

Economic objective function

The most commonly used objective in the OPF problem formulation is the minimization of the total operation cost of the fuel consumed for producing electric power within a schedule time interval (one hour). The individual costs of each generating unit is assumed to be function of only real power generation and are represented by quadratic curves of second order[1].

$$F_{ec}(x) = \sum_{i=1}^{ng}(a_i + b_i Pg_i + c_i Pg_i^2) \quad \$/h \quad (3)$$

Where a_i, b_i and c_i are the cost coefficients of generator at bus.

Emission objective function

In this study, Nitrogen-Oxide (NOx) emission is taken as the index from the viewpoint of environment conservation. The amount of NOx emission is given as a function of generator output (in Ton/hr), that is, the sum of quadratic and exponential functions.

$$F_E = \sum_{i=1}^{ng}(a_i + b_i Pg_i + c_i Pg_i^2 + d_i \exp(e_i Pg_i)) \quad \text{Ton/hr} \quad (4)$$

where a_i, b_i, c_i, d_i and e_i are the coefficients of generator emission characteristic.

The pollution control cost (in \$/h) can be obtained by assigning a cost factor to the pollution level expressed as

$$F_{pc} = wF_E \quad \$/h \quad (5)$$

where w is the emission control cost factor in \$/Ton.

Total cost objective function

The economic dispatch and emission dispatch are considerably different. The economic dispatch reduces the total fuel cost (operating cost) of the system at an increased rate of NOx. On the other hand emission dispatch reduces the total emission from the system by an increase in the system operating cost. Therefore it is necessary to find out an operating point, that strikes a balance between cost and emission.The CEED problem can be formulated as,

$$\text{minimize} f(F_{ec}, F_E) \quad (6)$$

subject to demand constraint and generating capacity limits.

By introducing the emission control cost factor w, the multiobjective function is converted to single objective function and can be stated as follows:

$$\text{minimize} \quad F = F_{ec} + wF_E \quad (7)$$

Types of constraints

The equality constraints are the power flow equations describing bus injected active and reactive powers of the $i\ th$ bus.

The active and reactive power injections at ith bus are defined in the following equation:

$$P_i = Pg_i - Pd_i = \sum_{j=1}^{nb} V_i V_j (g_{ij} Cos\theta_{ij} + b_{ij} Sin\theta_{ij}) \quad (8)$$

$$Q_i = Qg_i - Qd_i = \sum_{j=1}^{nb} V_i V_j (g_{ij} Cos\theta_{ij} - b_{ij} Sin\theta_{ij}) \quad (9)$$

where Qg_i is the reactive power generation at bus i; Pd_i, Qd_i are the real and reactive power demands at bus i; V_i,V_j, the voltage magnitude at bus *i*, *j*, respectively; θ_{ij} is the admittance angle, b_{ij} and g_{ij} are the real and imaginary parts of the admittance and nb is the total number of buses.

Types of inequality constraints

The inequality constraints of the OPF reflect the limits on physical devices in the power system as well as the limits created to ensure system security.

The inequality constraints on the problem variables considered include:

- Upper and lower bounds on the active generations at generator buses
  $Pg_i^{min} \le Pg_i \le Pg_i^{max}, \quad i = 1\ to\ ng.$
- Upper and lower bounds on the reactive generations at generator buses
  $Qg_i^{min} \le Qg_i \le Qg_i^{max}, \quad i = 1\ to\ ng$
- reactive power injections due to capacitor banks
  $Q_{Ci}^{\min} \le Q_{Ci} \le Q_{Ci}^{\max}, i = 1, \ldots, cs$
- Upper and lower bounds on the voltage magnitudes at all the buses.
  $V_i^{min} \le V_i \le V_i^{max}, \quad i = 1\ to\ nb.$
- Upper and lower bounds on the tap changes of linear tap changing transformers
  $T_i^{min} \le T_i \le T_i^{max}, \quad i = 1\ to\ nb.$

- Voltage stability index:
  $L_j \le L_j^{max}$, j=1,….,NL
- SVC susceptance constraint:
  $B_{SVC}^{min} \le B_{SVC} \le B_{SVC}^{max}$
- transmission lines loading
  $S_i \le S_i^{\max}, i = 1, \ldots, nl$

3. Particle Swarm Optimization in Optimal Power Flow

Particle Swarm Optimization Technique Search Mechanism of PSO

The inertia weight parameter is considered important for the convergence of the algorithm. The value of the inertia weight parameter is normally kept between 0.4 and 0.9. Thus, the choice of inertia weight should be carefully made.

Each position and velocity in the N dimensional space such as position $X_i = (x_{i1}, x_{i2}, x_{i3}, \ldots \ldots x_{in})$ and velocity $V_i = (v_{i1}, v_{i2}, v_{i3}, \ldots \ldots v_{in})$ Each particle is then flown over the search space in order its flying velocity and direction according to its own flying experience as well as that of its neighbors. Positions of the particles (tentative solutions) are evaluated at the end of every iteration relative to an objective or fitness value.

The collective best positions of all the particles taken together is termed as the global best position given as $gbest = (gb_1, gb_2, gb_3, \ldots \ldots gb_n)$ and the best position achieved by the individual particle is termed as the local best or position best and for the i_{th}particle given as $pbest = (p_{i1}, p_{i2}, p_{i3}, \ldots \ldots p_{in})$ .Particles use both of these information to update their positions and velocities as given in the following equations:

$$v_i^{(t+1)} = w_i . v_i^{(t)} + c_1 . r_1 . \left(x_{gbest}^{(t)} - x_i^{(t)}\right) + c_2 . r_2 . (x_{ipbest}^{(t)} - x_i^{(t)}) \qquad (10)$$

$$x_i^{(t+1)} = x_i^{(t)} + v_i^{(t+1)} \qquad (11)$$

where:

t : pointer of iterations (generations).

w_i: inertia weight factor.

c_1, c_2 : acceleration constant.

r_1, r_2 : uniform random value in the range (0,1).

$v_i^{(t)}$: velocity of particle i at iteration t.

$x_i^{(t)}$: current position of particle i at iteration t

$x_{ipbest}^{(t)}$: previous best position of particle i at iteration t.

$x_{gbest}^{(t)}$: best position among all individuals in the population at iteration t.

$v_i^{(t+1)}$: new velocity of particle i.

$x_i^{(t+1)}$: new position of particle i..

PSO applied to optimal power flow

The objective is to minimize the objective function of the OPF defined by (7), taking into account the equality constraints and the inequality constraints.

The cost function implemented in PSO is defined as:

$$F(x) = \left[\sum_{i=1}^{ng}\left(a_i + b_i P g_i + c_i P g_i^2\right)\right] + w . \left[\sum_{i=1}^{ng}\left(a_i + b_i P g_i + c_i P g_i^2 + d_i \exp(e_i P g_i)\right)\right] \$/h \qquad (12)$$

To minimize F is equivalent to getting a maximum fitness value in the searching process. The particle that has lower cost function should be assigned a larger fitness value.

The objective of OPF can be changed to maximization of fitness correspondingly as follows:

Maximize $fitness = 1/F$ (13)

In this method only the inequality constraints on active powers are handled in the cost function. The other inequality constraints are scheduled in the load flow process [5– 8]. Because the essence of this idea is that the inequality constraints are partitioned in two types of constraints, active constraints that effect directly the objective function are checked using the PSO-OPF procedure and the reactive constraints are updating using an efficient Newton-Raphson Load flow (NR) procedure.

PSO algorithm application to OPF

The PSO algorithm applied to OPF can be described in the following steps.

Step 1: Input parameters of system, and specify the lower and upper boundaries of each control variable.

Step 2: The particles are randomly generated between the maximum and minimum operating limits of the generators.

Step 3: Calculate the value of each particle using objective function.

Step 4: Evaluate the fitness value of objective function of each particle using (13). x_{ibest} is set as the i th particle's initial position; x_{gbest} is set as the best one of x_{ibest}. The current evolution is t =1.

Step 5: Initialize learning factorsc_1, c_2, inertia weight w_i and the initial velocityv_1.

Step 6: Modify the velocity v of each particle according to (10).
Step 7: Modify the position of each particle according to (11). If a particle violates its position limits in any dimension, set its position at proper limits. Calculate each particle's new fitness; if it is better than the previous x_{gbest}, the current value is set to be x_{gbest}.
Step 8: To each particles of the population, employ the Newton-Raphson method to calculate power flow and the transmission loss.
Step 9: Update the time counter $t = t + 1$.
Step 10: If one of the stopping criteria is satisfied then go to step 11. Otherwise go to step 6.
Step 11: The particle that generates the latest p_{gbest} is the global optimum

Voltage Stability Index (L-index) Computation:
The voltage stability L-index is a good voltage stability indicator with its value change between zero (no load) and one (voltage collapse). Moreover, it can be used as a quantitative measure to estimate the voltage stability margin against the operating point. For a given system operating condition, using the load flow (state estimation) results, the voltage stability L -index is computed as given in equation (17),

$$L_j = \left|1 - \sum_{i=1}^{g} F_{ji} \frac{V_i}{V_j}\right| \quad (17)$$
$$j = g+1, \dots\dots, n$$

4. Power Flow Including Facts Controllers

Shunt Variable Susceptance Model
In practice the SVC can be seen as an adjustable reactance with either firing-angle limits or reactance limits. The equivalent circuit shown in Figure 2 is used to derive the SVC nonlinear power equations and the linearized equations required by Newton's method[9].

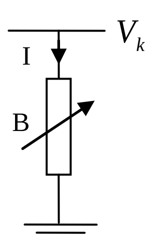

Figure 1: Variable Shunt Susceptance

With reference to Figure 1, the current drawn by the SVC is

$$I_{SVC} = jB_{SVC}V_k (18)$$

and the reactive power drawn by the SVC, which is also the reactive power injected at bus k, is

$$Q_{SVC} = Q_k = -V_k^2 B_{SVC} (19)$$

The linearized equation is given by (20), where the equivalent susceptance B_{SVC} is taken to be the state variable:

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \end{bmatrix}^{(i)} = \begin{bmatrix} 0 & 0 \\ 0 & Q_k \end{bmatrix}^{(i)} \begin{bmatrix} \Delta\theta_k \\ \Delta B_{SVC}/B_{SVC} \end{bmatrix}^{(i)} (20)$$

At the end of iteration (i), the variable shunt susceptance B_{SVC} is updated according to

$$B_{SVC}^{(i)} = B_{SVC}^{(i-1)} + \left(\frac{\Delta B_{SVC}}{B_{SVC}}\right)^{(i)} B_{SVC}^{(i-1)} (21)$$

The changing susceptance represents the total SVC susceptance necessary to maintain the nodal voltage magnitude at the specified value.

In the present work the SVC is located at 26th bus as the voltage deviations at that bus is maximum.

IEEE 30 bus system Data

Table 1: Power generation limits and cost coefficients of IEEE 30-bus system

Bus	Pg_{min}	Pg_{max}	a_1 (\$/hr)	b_1 (\$/hr)	c_1 (\$/hr)
01	0.5	2.0	37.5	200	0
02	0.2	0.8	175	175	0
03	0.15	0.5	625	100	0
04	0.1	0.35	83	325	0
05	0.1	0.3	250	300	0
06	0.12	0.4	250	300	0

Table 2: Pollution coefficients for IEEE 30-bus system

Bus	a ton/hr $*10^{-2}$	b ton/hr $*10^{-2}$	c ton/hr $*10^{-2}$	d ton /hr $*10^{-4}$	e
1	4.091	-5.554	6.490	2.00	2.857
2	2.543	-6.047	5.638	5.00	3.333
3	4.258	-5.094	4.586	0.01	8.000
4	5.326	-3.550	3.380	20.00	2.000
5	4.258	-5.094	4.586	0.01	8.000
6	6.131	-5.555	5.151	10.00	6.667

Table 3: Parameters and their values in this paper

Parameter	Value taken
Emission control cost factor, *w*	550.66 $/ton
total load demand	2.834 p.u
no. of generations	100
no. of particles	6
population size	50
Cognitive constant, c_1	2
Social constant, c_2	2
No. of SVCs	1

5. Results & Graphs

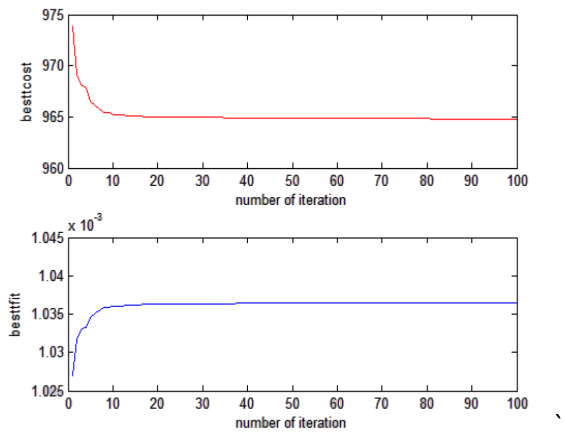

Figure 2: Global cost and fitness curves of IEEE 30 bus system without SVC for 100 iterations

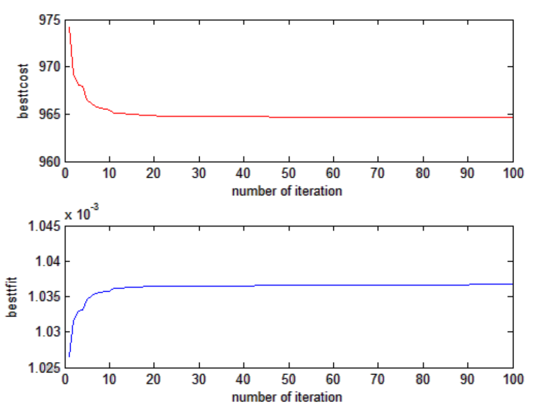

Figure 3: Global cost and fitness curves of IEEE 30 bus system with SVC for 100 iterations

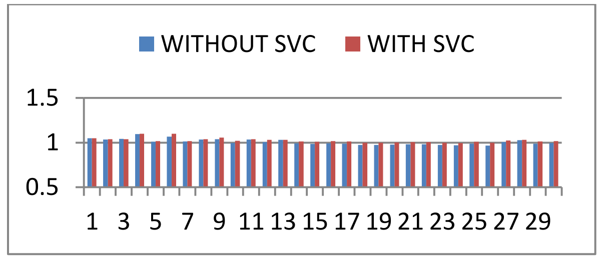

Figure 4: Voltage profile of IEEE 30 bus system with and without SVC

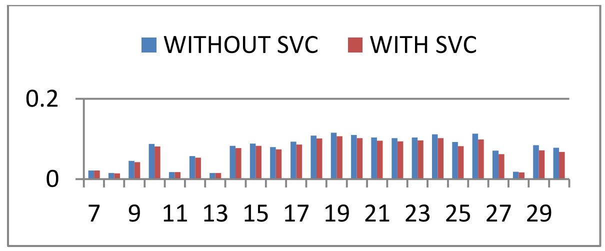

Figure 5: Voltage stability index of IEEE 30 bus system with and without SVC

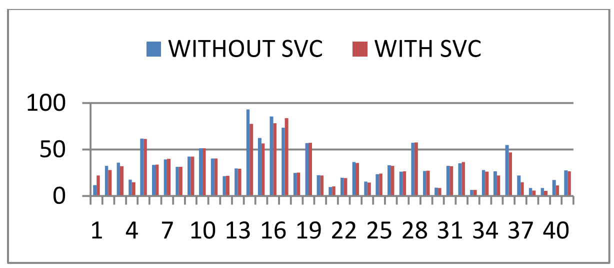

Figure 6: MVA loading of IEEE 30 bus system with and without SVC

On installation of SVC, from fig 4,5 and 6, it can be observed that on installing Shunt Var Compensator (SVC) at 26th bus the voltage profile improved to 1p.u and also voltage levels at all other buses have improved; the stability index approached further closer to zero and finally, the MVA loading on transmission lines is observed to decrease at almost all the buses on installation of SVC.

Table 4: Comparison of Results Obtained

Parameter	Without SVC	With SVC
Total cost ($/hr)	965.7238	965.3164
Fuel cost($/hr)	816.7049	818.1669

Emission(ton/hr)	0.2706	0.2672
Real power loss (pu)	0.0598	0.0574

Table 5: Comparison of performance parameters without and with SVC

Parameter	Without FACTS	With SVC
PG1	1.3206	1.2978
PG2	0.5781	0.5873
PG3	0.2487	0.2515
PG4	0.3000	0.3000
PG5	0.2434	0.2535
PG6	0.2030	0.2015
VG1	1.0500	1.0500
VG2	1.0446	1.0443
VG3	1.0321	1.0296
VG4	1.0995	1.1000
VG5	1.0166	1.0166
VG6	1.0644	1.0986
Tap - 1	0.9687	0.9523
Tap - 2	1.0550	1.0141
Tap - 3	1.0673	1.0637
Tap - 4	0.9739	0.9928
Q_{C10}	0.0692	0.0576
Q_{C12}	0.0850	0.0776
Q_{C15}	0.0000	0.0076
Q_{C17}	0.0219	0.0145
Q_{C20}	0.0052	0.0022
Q_{C21}	0.0000	0.0000
Q_{C22}	0.0000	0.0007
Q_{C23}	0.0000	0.0019
Q_{C29}	0.0249	0.0053
L_{jmax}	0.1155	0.107

6. Conclusion & Future scope

In this paper the fuel cost and emission are combined into a single function and the load dispatch for minimum of the total objective function are obtained. SVC is installed in the IEEE 30 bus system and the stabilized voltages and reduction MVA loading of the transmission lines has been observed. PSO technique is employed as it possesses advantages of modelling flexibility, sure and fast convergence, less computational time over other heuristic methods. Further this work can be extended over to other FACTS devices.

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