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Risk Analysis and Economic Load Dispatch Evaluation of Network with High Wind Power Penetration

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Abstract

This study based on investigation for integration wind power into conventional power system with its impact on fossil fuel generators and their generation management. Wind power as environmental friendly energy source can reduce the operational cost of the system due to considering no cost for energizing the generator in comparing with fossil fuel generators. However due to unpredictable nature of the wind power, it is quite difficult to determine how much wind power should be integrated to ensure both power system security and operational cost reduction. In this study by comparing both economic and security requirements using GA and PSO for smart calculation in wind power generation into the conventional system, a proper economic load dispatch program has been applied. Three different approaches (pessimistic, Optimistic and Linear) has been studied and compared to evaluate the system security and reliability with economic benefits. Due to considering no fuel cost for wind power generators, it is more beneficial to produce electrical power by this type of power resource but with more reliability for the system. At the end by comparing PSO and GA results and numerical analysis on IEEE-30 bus test system with six generator, exactitude and accuracy of the proposed approaches presented.

Keywords: Wind Power Generation, Economical load Dispatch, Wind Power Penetration, Security Concerns, Risk Evaluation, Smart Analysis, PSO, GA

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1. Introduction

By increasing attention in using sustainable energy sources like wind and solar power, using these new power generation sources are not negligible. Economic load dispatch, schedule the power generation in order to minimize the total operational cost. But sustainable energy sources have an unpredictable nature so programming their power generation into a specific schedule time is a complex problem. Security concern is one of the main issues which need more attention, when unpredictable wind power generation can endanger the whole system. Economic load dispatch (ELD) is a scheduling to program the power generation in appropriate manner to satisfy the load demand while minimizing the total operational cost. By increasing and development in renewable energy sources in recent years, using these types of clean energy with zero cost for fuel, are rapidly increasing. Wind power generators not only reduce the cost of generation but also reduce the transmission losses. One of the main issues in using wind power due to intermittency and unpredictable nature of the wind is security problems. When wind power penetration into the traditional system exceeds certain level, fluctuation in wind power output and the unpredictability can lead to power outage or unstable system. To achieve a reasonable definition between operation cost of the system and risk level for a suitable dispatch schedule in power system effective and powerful optimization procedure is needed. In this study to indicate system security level in terms of wind power penetration and wind power cost, due to intermittent nature of the wind power generation, fuzzy membership has been applied. This paper is organized as follows: sections 2 and 3 describe the PSO and GA algorithm respectively, while wind power penetration model described by fuzzy membership functions, presented in section 4. The formulation of dispatch problem has been presented in section 5. At the end the results and analysis are presented and compared with other paper.

2. Particle Swarm Optimization

Particle Swarm Optimization (PSO) is a population based stochastic optimization technical developed in 1995 by Dr. Ebehart and Dr. Kennely, inspired by social behavior of bird flocking or fish schooling. PSO is a population based search method i.e. it moves from a set of points with likely improved in every iteration. PSO uses a population of solution called particles, which fly through the search space with directed velocity vectors to find a better solution [8]. Each particle keeps track of its co-ordinates in the problem space which are associated with the best solution (fitness) it has achieved so far. This fitness value is stored. This value is called the pbest (personal best). Another "best" value that is tracked by the particle swarm optimizer is the best value obtained so far by any particle in the immediate neighborhood of the particle. This location is called lbest (local best). When a particle takes all the population as its topological neighbors, the best value is called the gbest (global best). PSO concept consists of at each time step changing the velocity (accelerating) of each particle toward its pbest and ibest location. Acceleration is weighted pbest a random term with separate random numbers being generated for acceleration toward pbest and ibest locations. The velocity of the particle is given by [5]:

$$V_i^{(u+1)} = w \times V_i^{(u)} + C_1 \times rand() \times \left(pbest_i - P_i^{(u)}\right) + C_2 \times rand() \times (gbest_i - P_i^{(u)}) \quad (1)$$

And the position is given by:

$$P_i^{(u+1)} = P_i^{(u)} + V_i^{(u+1)} \quad (2)$$

The term rand ()$\times$ $(pbest_i - P_i^{(u)})$ is called particle memory influence. The term rand ()$\times$ $\left(gbest_i - P_i^{(u)}\right)$ is called swarm influence. $V_i^{(u)}$ Which is the velocity of i[th] particle at iteration "u" must lie in the range

$$V_{min} \leq V(u)_i \leq V_{max} \quad (3)$$

The parameter V_{max} determines the resolution, or fitness, with witch regions are to be searched between the present position and the target position. If V_{max} is too high, particles may fly past good solutions. If V_{min} is too small, particle may not explore sufficiently beyond local solutions. V_{max} is often set at 10-20% of the dynamic range on each dimention. The constants C_1 and C_2 pull each particle towards pbest and gbest positions. Low value allow particles to roam far from the other hand, high value result in abrupt movement towards, or past, target regions. The acceleration constant C_1 and C_2 are often set to be 2.0. Suitable selection of inertia weight "w" provides a balance between global and local explorations thus requiring less iteration on average to find a sufficiently optional solution. The inertia weight W is set according to the following equation:

$$W = W_{msx} - \left[\frac{W_{max} - W_{min}}{ITER_{mx}}\right] \times ITER \quad (4)$$

Where W is the inertia weighting factor, W_{max} is maximum value of weighting factor, W_{min} is minimum value of weighting factor, $ITER_{max}$ is maximum number of iterations and ITER is current number of iteration [5, 7].

2.1 proposed algorithm steps:

The sequential steps to find the optimum solution follow:

Step 1: the power of each unit, velocity of particle, is randomly generated which must be in the maximum and minimum limit. These initial individuals must be feasible candidate solutions that satisfy the practical operation constraints.

Step2: each set of solution in the space should satisfy:

$$\sum_{i=1}^{N} P_g = P_D + P_L \quad (5)$$

Where $P_{L=}$Pgg$\times Bu \times Pgg' + B0 \times Pgg' + B00u$

Step3: the cost function of each individual Pgi, is calculated in the population using the evaluation function F. here F is:

$$F = a \times (P_{gi}^2) + b \times P_{gi} + c \quad (6)$$

Where a,b and c are constants. The presented value is set as the pbest value.

Step4: each pbest values are compared with the other pbest values in the population. The best evaluation value among the bpest is denoted as gbest.

Step5: the member velocity V of each individual Pg is updated according to the velocity update equation

Step6: the velocity component constraint occurring in the limits from the following conditions are checked

$Vd_{min} = -0.5\times P_{min}$

$Vd_{max} = +0.5\times P_{max}$

Step7: the position of each individual Pg is modified according to the position update equation:

$$Pgid(u+1) = Pgid(u) + Vid(u+1) \quad (7)$$

Step8: the cost function of each new is calculated if the evaluation value if each individual is better than previous pbest, the current value is set to be pbest. If the best pbest is better than gbest, the value is set to be gbest [5].

Step 9: if the number of iterations reaches the maximum, then go to step 10. Otherwise go to step 2.

Step10: the individual that generates the latest gbest is the optimal generation power of each unit with the minimum total generation cost.

3. Genetic Algorithm

Genetic algorithms are stochastic search techniques based on the mechanism of natural selection and survival of the fittest. Further, they exchange information among solutions to arrive at global optimum. More importantly, Gas appears attractive because of their superior robust behaviour in nonlinear environment compared to other optimization techniques. The architecture of GA implementation can be divided into three phases namely:

1. Initial population generation
2. Fitness evaluation and
3. Genetic operation

GA optimization process is binary encoding which concerns the specification of the number of bits of each string to simulate the genes of an individual chromosome in which, the key computational tasks of GA are briefly highlighted.

1. Population size
2. Crossover and
3. Mutation

Probabilities of these parameters are selected, and an initial population of binary strings of finite length is randomly generated. Each of these individuals, comprising a number of chromosomes, represents a feasible solution to the search problem, the strings are then decoded back into their control variables to assess their fitness [1]. If a pre-defined convergence criterion is not satisfied, then the genetic operation comprising selection and repopulation, crossover and mutation are carried out. Fundamentally, the selection and reproduction mechanism attempts to apply pressure upon the population in a manner similar to that of natural selection found in biological systems. A new population is created with poorer performing individuals eliminated while the most highly fit members in a population are selected to pass n information to the next generation. The widely used selection strategies are stochastic tournament and roulette wheel selection. Conceptually, pairs of individuals are chosen at random from the population and the fit of each pair is allowed to mate. Each pair of mates creates a child having some mix of the two parents' characteristics according to the crossover method. The process of randomly selecting pairs and mating the stronger individuals continues until a new generation of the same number of individuals is reproduced. The crossover previously mentioned is the kernel of genetic operation. It promotes the exploration of new regions in the search space using randomized mechanism of exchanging information between strings. The other work considered is the mutation process of randomly changing encoded bit information for a newly created population individual. Mutation is generally considered as a secondary operator to extend the search space and cause escape from a local optimum when used along with the selection and crossover schemes. Due to the probabilities nature of the generation process, there exists a possibility that the genetic operations may destroy the highest fit individual. The elitist strategy ensures that the fittest individual generated actually is reproduced in the subsequent generation. Elitism can rapidly increase the GA performance by using the best solution as a seed for future optimization thus accelerating its convergence speed to global optimum.

3.1 Mechanism of GA Optimization:

Ga is a global search algorithm based on biological concept which mimic the mechanics of nature and natural genetics, compared to traditional methods, GA has several differences, such as it searches many candidates solution is parallel, not a single point, use probabilities transition rules using GA operators rather than deterministic ones, it does not require other auxiliary knowledge, except objective or fitness function and attractive property of GA is the high probability of finding a global optimum [1].

3.2. Algorithm Steps:

The main steps involved. In this optimization procedure are mentioned as follows:

Step1: Initialization process in this step all the global, generating unit parameters are initialized.

Step2: GA initial process. In this step all the genetic parameters like, chromosome length, population size, convergence, number of iterations, crossover and mutation probabilistic are initialized.

Step3: GA solving process. In this step GA solving procedure is done like, evaluating the fitness value for each chromosome, genetic evaluation using selection method and GA operator, production of offspring population, etc.

Step4: convergence checking. In this step the convergence criterion is checked, if it is satisfied result is produced, else it goes to step 3 for further calculations.

4. Wind Power Penetration Formula

Wind power integration is an important issue to address for achieving a reliable power system including wind power source. Because of the unpredictable and variable characteristic of wind power, its integration into the traditional thermal generation systems will incur the operator’s concern on system security [1]. Fuzzy definition regarding wind penetration is a viable way to represent the penetration level of the wind power, since it is usually difficult to determine the optimal wind power that should be integrated into the conventional power grids. As shown in Fig. 1, a fuzzy membership function μ regarding the wind penetration is defined to indicate the system security level. The mathematical expression for μ comes as follow [1-3]:

$$\mu = \begin{cases} 1 & Wc \le Wc(P_{Dmin}) \\ \frac{Wc_{max} - Wc}{Wc_{max} - Wc_{min}} & Wc_{min} \le Wc \le Wc_{max} \\ 0 & Wc \ge Wc(P_{Dmax}) \end{cases} \quad (8)$$

Where W is the wind power incorporated in economic dispatch, $W(P_{Dmin})$ is the lower bound of wind power penetration, below which the system is defined secure, $W(P_{Dmax})$ is the upper bound of wind power penetration above which the system is considered as insecure due to the wind penetrations. Both $W(P_{Dmin})$ and $W(P_{Dmax})$ are dependent on the total load demand in the power dispatch. The above defined membership function can also be represented in term of the operational cost for incorporating wind power [1-3]:

$$\mu = \begin{cases} 1 & Wc \le Wc(P_{Dmin}) \\ \frac{Wc_{max} - Wc}{Wc_{max} - Wc_{min}} & Wc_{min} \le Wc \le Wc_{max} \\ 0 & Wc \ge Wc(P_{Dmax}) \end{cases} \quad (9)$$

Where Wc is the running cost of wind power in the power dispatch, $Wc(P_{Dmin})$ is the lower bound cost for producing wind power, below which the system is seen as secure; $W(P_{Dmax})$ is the upper bound cost for including wind power, above which the system is considered as insecure due to the wind intermittency [4, 6]. In a similar way, both $Wc(P_{Dmin})$ and $Wc(P_{Dmax})$ are dependent on the total load demand in the power dispatch. In this study, sensitivity studies are also carried out to illustrate the impact of different allowable ranges of wind power penetration as well as different running costs of wind power on the obtained final solution .

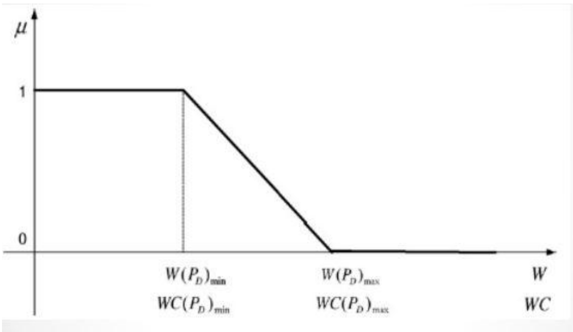

Fig.1. Fuzzy linear representation of the security level in term of wind penetration and wind power cost [1]

To reflect dispatcher’s differing attitudes toward wind power penetration, a quadratic membership function is defined in (10). Note that here the attitude of the dispatcher refers to a corporate strategic or tracial plan that views wind power penetration with a pessimistic or optimistic attitude.

$$\mu = \begin{cases} 1 & W \le W(P_{Dmin}) \\ a_W W^2 + b_W W + c_W & W_{min} \le W \le W_{max} \\ 0 & W \ge W(P_{Dmax}) \end{cases} \quad (10)$$

Where a_w, b_w, and c_w are the coefficient of the quadratic function, which determine its curve shape reflecting the dispatcher’s attitude toward wind power. As shown in Fig. 2, by selecting different coefficients a_w, b_w and c_w, different curve shapes of the quadratic can be defined. For the identical security level μ0, the penetration levels of wind power differ for different defined functions W_1, W_2 and W_3. The curves corresponding to these three values reflect the pessimistic, neutral and optimistic attitudes of the dispatcher toward the wind power integration of the dispatcher toward the wind power

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integration, respectively [4]. In a similar way, the security level can also be defined in term of the operational cost of wind power [1-3,6].

$$\mu = \begin{cases} 1 & Wc \le Wc(P_{Dmin}) \\ a_c Wc^2 + b_c Wc + c_c & Wc_{min} \le Wc \le Wc_{max} \\ 0 & Wc \ge Wc(P_{Dmax}) \end{cases} \quad (11)$$

Where a_c, b_c and c_c determine the curve shape of the quadratic function defined in term of the running cost of wind power.

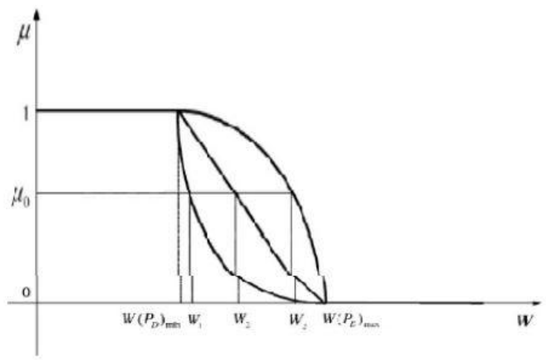

Fig.2. Fuzzy quadratic representation of the level in term of wind power penetration [1].

5. Dispatch Problem Formulation

The dispatch model in the simulation uses centralized dispatch in a deregulated power system. Generators in the systems are thermal; wind constraints included in the calculation are the maximum and minimum values of generator output, the ramp rate of the generators, and reverse requirements. For simplification, transmission losses are neglected. The economic dispatch process aims at cost minimization subject to these constraints. The problem of economic power dispatch with wind penetration consideration can be formulated as a bi-criteria optimization model. The two conflicting objective, i.e. total operational cost and system risk level should be minimized simultaneously while fulfilling certain system constraints. This bi-objective optimization problem is formulated mathematically in this section [1].

3.1. Problem Objectives

There are two objectives that should be minimized simultaneously, that is, system risk level and the total operational cost.

Objective1: Minimization of System Risk Level

From the security level function defined in (8) and (9), we know that the larger the value of membership function μ is, the more secure the system will become. If the wind penetration is restricted under a certain level, the system can be considered as secure. On the contrary, if excessive wind penetration is introduced into the power dispatch, the system may become insecure. Here we define an objective function which should be minimized in order to ensure system security:

$$R(\mu) = \frac{1}{\mu} \quad (12)$$

Objective2: Minimization of Operational Cost

The cost curves of different generators are represented by quadratic functions with sine components. The superimposed sine components represent the valve openings. The total $/h fuel cost FC (PG) can be represented as follows:

$$FC(PG) = \sum_{i=1}^{M} a_i + b_i \times PG_i + c_i \times PG_i^2 \quad (13)$$

Where M is the number of generators committed to the operating system, a_i , b_i and c_i are the cost coefficients of the i^{th} generators. PG_i is the real power output of i^{th} generator. PG is the vector of real power outputs of generators and defined as:

$PG=[PG_1, PG_2, PG_3, \ldots\ldots, PG_M]$

The running cost of wind power can be represented in term of the value of membership function μ which indicates the system security level. For the linear membership function case:

$$Wc(P_G,\mu) = C_W(W_{av} - (P_D + P_L - \textstyle\sum_i^M PG_i)) - \mu \times \Delta Wc + Wc_{max} \quad (14)$$

Where W_{av} is the available wind power from the wind farm, C_w the coefficient of penalty cost for not using all available wind power, P_D the load demand, P_L is the transmission loss and ΔWc is as following equation, $\Delta Wc = Wc_{max} - Wc_{min}$.

For the quadratic membership function case:

$$Wc(P_G,\mu) = C_W(W_{av} - (P_D + P_L - \textstyle\sum_i^M PG_i)) - \frac{b_C}{2a_C} \pm \sqrt{\frac{\mu - (C_C - (b_C^2/4a_C))}{a_C}} \quad (15)$$

The sign of the last term is determined by the curve shape of the defined quadratic function. Thus, the total operation cost TOC can be calculated as:

$$TOC(P_G,\mu) = FC(P_G) + Wc(P_G,\mu) \quad (16)$$

3.2. Problem Constraints

Due to the physical or operational limits in practical systems, there is a set of constraints that should be satisfied throughout the system operations for a feasible solution.

Constrain1: Generation Capacity Constraint:

For normal system operations, real power output of each generator is restricted by lower and upper bounds as follows:

$$P_{min} \leq PG_i \leq P_{max} \quad (17)$$

Where $P_{min}\,G_i$ and $P_{max}\,G_i$ are the minimum and maximum power from generator I, respectively.

Constraint2: Power Balance Constraint:

The total power generation and the wind power must cover the total demand P_D and the real power loss in transmission lines P_L. for the linear membership function, this relation can be represented by:

$$\sum_{i=1}^{M} PG_i + W_{max} - \mu \times \Delta W = P_D + P_L \quad (18)$$

For the quadratic membership function, the relation can be expressed by [9]:

$$\sum_{i=1}^{M} PG_i - \frac{b_w}{2a_w} \pm \sqrt{\frac{\mu - (C_w - (b_w^2/4a_w))}{a_w}} = P_D + P_L \quad (19)$$

In (19) the sign of the last term is determined by the curve shape of the defined quadratic function.

The transmission losses can be calculated based on the Kron's loss formula as follows:

$$P_L = \sum_{i=1}^{M}\sum_{i=1}^{M} PG_i \times B_{ij} \times PG_j + \sum_{i=1}^{M} B_{0i} \times PG_i + B_{00} \quad (20)$$

Where B_{ij}, B_{0i} and B_{00} are the transmission network power loss B-coefficients. It should be noted that the transfer loss of the wind power is not considered in this study [1].

Constraint3: Available Wind Power Constraint

The wind power used for dispatch should not exceed the available wind power from the wind park [9]:

$$0 \leq P_D + P_L - \sum_{i}^{M} PG_i \leq W_{av} \quad (21)$$

Constraint4: Security Level Constraint

From the definition of membership function shown from (8) to (10), the value of μ should be within the interval of [0, 1]:

$$0 \leq \mu \leq 1 \quad (22)$$

6. Case studies

As illustrated in Fig. 3.a 33bus test system with 6 generators has been considered. GA and PSO applied for compression the cost, risk level and achieve optimal generator schedule with wind penetration. Amount of generated power for each generator and wind power output, illustrated as Fig.3.

Table.1, shows the compression of cost, risk level and optimal generator scheduling for the test system for PSO. Table.2, shows the results for GA as an optimal algorithm.

In compression between PSO and GA, PSO has better and more accurate results with less total operational cost and higher in risk level. Higher risk means less reliable and unsafe schedule. In compression between study in this paper and [1], this study has improved the results. Table 3. Shows this compression for Total operational cost ($/hr) and risk level for all optimistic, linear and pessimistic approaches.

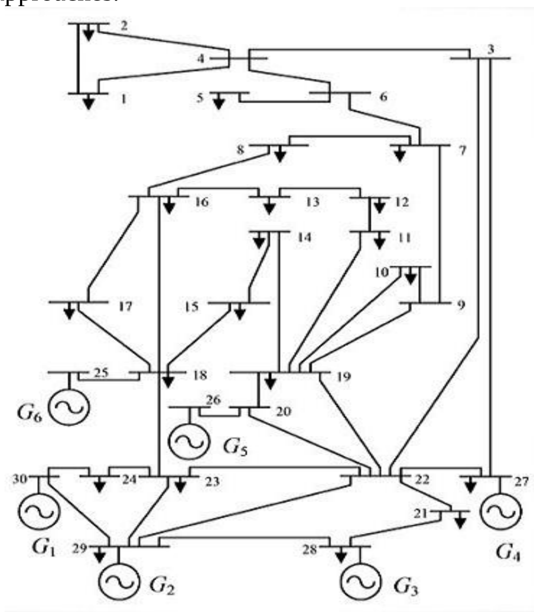

Fig. 3. 33 bus test system [1]

Table.1.
PSO results in different approaches

Generator PG_i and Wind (MW)	Optimistic Approach	Linear Approach	Pessimistic Approach
PG1	13.1726	21.035	10.49
PG2	26.64	40.667	31.731
PG3	30.5311	26.3411	54.941
PG4	78.543	78.01	83.29
PG5	47.20	38.30	35.635
PG6	35.12	28.42	16.28
Wind	52.63	53.37	54.32
Total Operational Cost ($/hr)	**775.771**	**790.535**	**795.632**
Risk Level	5.51	5.92	6.23
a_w	-9.96	---	4.98
b_w	4.94	---	-7.76
c_w	0.4	---	2.8

7. Conclusion

This study investigates the integration of wind power generation into conventional power system with its impact on fossil fuel generators and their generation management. Although wind power as environmental friendly energy source can reduce the operational cost of the system due to considering no cost for energizing the generator in comparing with fossil fuel generators but due to unpredictable nature of the wind, it is quite difficult to determine how much electrical power can be executed from the wind generator to ensure both power system security and operational cost reduction. A fuzzy representation of system security in term of wind power penetration level and operational costs has been applied to construct economic dispatch models. Finally in comparison between two proposed Algorithms (GA and PSO) the PSO results are more accurate and perform a better compilation between risk level and operational cost to achieve desirable OPF scheduling.

Table.2.
GA results in in different approaches

Generator PG_i and Wind (MW)	Optimistic Approach	Linear Approach	Pessimistic Approach
PG1	13.1726	21.035	11.00
PG2	26.64	40.667	32.61
PG3	30.5311	26.3411	56.04
PG4	78.543	78.01	84.29
PG5	47.20	38.30	35.42
PG6	35.12	28.42	16.32
Wind	53.38	52.08	50.88
Total Operational Cost ($/hr)	782.562	793.017	798.128
Risk Level	5.6719	5.9522	6.0819

Table.3.
Compression of result for PSO algorithm

	Optimistic Approach	Linear Approach	Pessimistic Approach
Total Operational Cost ($/hr)	775.771	790.535	795.632
Total Operational Cost ($/hr) in [1]	788.98	793.24	799.17
Risk Level	5.51	5.92	6.23
Risk Level in [1]	5.49	5.87	6.19

Table.4.
Compression of result for GA algorithm

	Optimistic Approach	Linear Approach	Pessimistic Approach
Total Operational Cost ($/hr)	782.562	793.017	798.128
Total Operational Cost ($/hr) in [1]	795.771	799.535	801.632
Risk Level	5.3933	5.7222	5.8411
Risk Level in [1]	5.5862	5.8665	5.9861

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