

Security constrained optimal power flow by modern optimization tools

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Abstract

In this paper, two approaches are studied for scheduling the power generators of the least cost. This is called security constrained optimal power flow [SCOPF]. This problem is represented as a two stage, security constrained OPF problem, in which the first stage optimizes the problem using a genetic algorithm for the purpose of comparison, while the second stage optimizes the problem of each contingency using flower pollination algorithms (FPA) as a new trend. Case studies based on IEEE 30 bus system show that the discussed techniques are advantageous and can guarantee operational reliability and economy.

Keywords: Optimal power flow, security, genetic algorithm, flower pollination algorithm

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1. Introduction

The faults and disturbances can cause unexpected outages in any power system. These are called contingencies which may lead to significant overloading with power system elements. The essential role of power system control is to keep any power system in secure state or to prevent the power system moving into emergency state at all operating conditions and this will improve the security of the system (Alsac and Scott, 1973; Mithun et al., 2010). The main objective of an optimal power flow (OPF) functions is to optimize this function which is subjected to some constraints. These constraints are divided into equality constraints as power balance equations and inequality constraints as the breaking points of control factors (Gaing and Chang, 2006). Some control measures should be done to keep the power system secure at the minimum cost to achieve the Security Constraint Optimal Power Flow (NIU and WAN, 2014). An answer of OPF problem can improve a particular target in working the power system by maximizing or minimizing concerning distinctive imperatives. Security constrained optimal power flow includes also outages of transmission lines and equipment. To get faster solutions, more effort should be done due to the complexity of the problem. Considerable measures of old strategies have been used as a part of understanding it.

These include the linear programming (Lima et al., 2003; Tuaimah and Meteb, 2014), gradient method (Salgado et al., 2002), interior point (IP) method (Capitanescua and Wehenkel, 2013) and Newton method (Tinney and Hart, 1967). The inequality constraints add complexity in dealing with gradient and Newton methods. The objective function is to be represented by linear equations and this leads to loss of accuracy in linear programming method. Recently global optimization strategies such as the genetic algorithm (Paranjothi and Anburaja, 2002; Singh and Verma, 2012), particle swarm (Turkay and Cavadag, 2013), tabu search (Abido, 2002a) and harmony search algorithm (HSA) (Sivasubramani and Swarup, 2011) have been utilized to solve the optimal power flow problem. Walters and Sheble (1993) presented an enhanced GA based OPF strategy with the individual made of paired control factors to enhance the framework security. Abido (2002b) presented the use of a PSO-based OPF technique with the individual of constant control factors structure for tackling the OPF issue with the smooth fuel cost of generator. In this paper, two optimization techniques are introduced for solving the obliged OPF problems, genetic algorithm, and flower pollination algorithm (FPA). In the discussed methods, the characteristics of the techniques and purpose are introduced in detail. The viability of the examined strategies is shown for the IEEE 30-bus system.

2. Problem Formulation

The optimal power flow is compelled improvement problem requiring the minimization of

$$f(x, u) \tag{1}$$

Subject to conditions

$$G_i(x, u) = 0 \dots \dots i = 0,1,2,3, \dots m \text{ [equality constrained] } \tag{2}$$

$$H_i(x, u) = 0 \dots \dots i = 0,1,2,3, \dots m \text{ [inequality constrained] } \tag{3}$$

$$u_{min} \leq u \leq u_{max}$$

$$x_{min} \leq x \leq x_{max} \tag{4}$$

The vector x incorporates every reliant variable which is bus voltage extents and stage points, and additionally the Mvar yield of Generators allocated for bus voltage control and settled parameters as the non-controlled Generator MW and Mvar yields, non-controlled MW and Mvar loads, settled bus voltages, line parameters,

2.1 Objective Function: In SCOPF, the fundamental object is to minimize add up to framework cost keeping the system security. At the point when the load is light, the least expensive generators run firstly, then when it expands, more costly generators work. Figure 1 shows input-output curve of a generator. It has a relation between output power in MW and input fuel to the generator in BTU [British Thermal Units per hour].

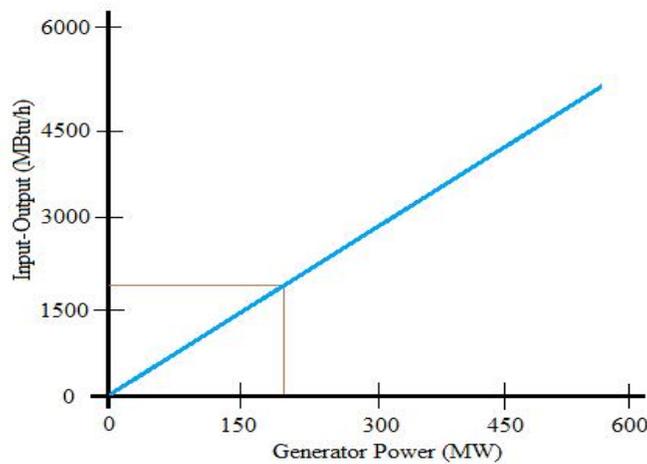


Figure 1.Input-output curve of a generator

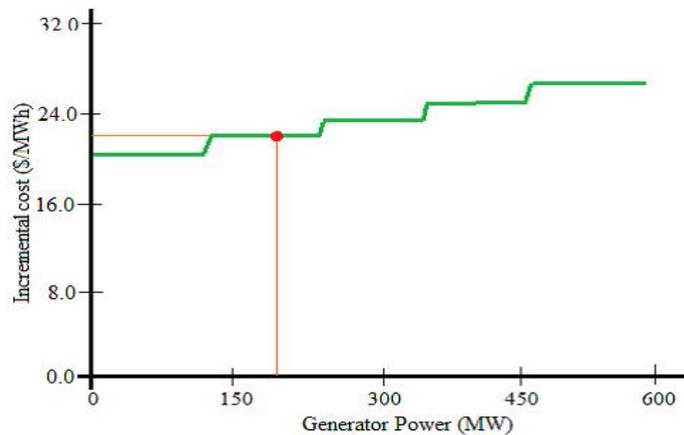


Figure 2.Incremental cost curve

In all practical cases, the cost of generator i can be represented as

$$C_i = a_i + b_i p_i + c_i p_i^2 \tag{5}$$

where p_i is the real output of a generator i and a_i, b_i, c_i are the coefficients of the cost function.

2.2 Control Variables: The estimation of control factors can be straightforwardly conformed to minimize the target work and fulfill the requirements. The control factors can be given as active and reactive power, add up to exchange, control voltage settings, Phase-shifter points, line streams of the transmission and the tap setting of LTC transformer.

2.3 Dependent Variables: The uncontrolled variables of an optimal power flow which are free, within limits as the magnitude and the angle of bus voltage.

2.4 Equality Constraints: The equality constraints of the OPF represent the power framework material science by the power stream conditions and this implies the whole of net infusion of genuine and receptive power at every bus breaks even with zero. This can be accomplished by dynamic and responsive power examination.

$$P_i = P_{load} + P_{loss} \tag{6}$$

$$Q_i = Q_{load} + Q_{loss} \tag{7}$$

Where P_i and Q_i are the real and reactive power outputs, P_{load} and Q_{load} are the real and reactive load power and P_{loss} and Q_{loss} are the real and reactive power loss.

2.5 Inequality Constraints: The working security breaking points can minimize the cost work inside these cutoff points

$$P_{gimin} \leq P_{gi} \leq P_{gimax} \tag{8}$$

$$Q_{gimin} \leq Q_{gi} \leq Q_{gimax} \tag{9}$$

$$\sum P_{gi} - P_D - P_{loss} = 0 \tag{10}$$

where P_{gi} is the real power of the generator i in MW, Q_{gi} is the amount of generation in Mvar at generator i

The inequality constraints on voltage magnitude V of each PQ bus is $V_{imin} \leq V_i \leq V_{imax}$ where V_{imin} and V_{imax} are the base and most extraordinary estimations of voltages at transport i (Kumar and. Sasikumar, 2015)

3. Security Constrained OPF

Security-Constrained OPF (SCOPF) problems are a unique class of OPF problems. It repeats between a base case OPF issue and an arrangement of predefined possibility framework states. To guarantee the security of system, a supposed "N-1 criteria" is connected, i.e. there ought to be no infringement after the blackout of any single component in the framework. This leads to the implementation of preventive mode of SCOPF. See that there are c contingencies to be tended to in the SCOPF, and that there are an entire new arrangement of requirements for each of these c possibilities. Watch:

- I. Every arrangement of possibility related uniformity requirements is precisely similar to the first arrangement of correspondence imperatives.
- II. Every arrangement of possibility related imbalance imperatives is precisely similar to the first arrangement of disparity aside from it compares to the framework with a component expelled and, for branch stream limitations and for voltage magnitudes, the points of confinement will be distinctive.

4. Optimization Algorithms

4.1. Genetic Algorithm: It is one of generalized search algorithms which rely on upon the mechanics of hereditary qualities (Devaraj and Yeganarayana, 2005). Genetic Algorithms (GA) consist of a populace of people that are called candidate solutions. They join arrangement assessment with stochastic hereditary administrators to keep up optimally for the goal work.

4.2. Flower Pollination:

4.2.1 Pollination

It is characterized as propagation of plants and this happens by gametes union. The gametes are characterized into male which creates the dust grains and female which produces ovules brone. The union happens by exchange the dust to the disgrace. The fertilization of the power is the exchange and testimony of grains from anther to disgrace. The fertilization is a fundamental operation in farming to deliver seeds and organic products. The fertilization is divided into self and Cross Pollination. The self

pollination happens when the pollination occurs at the same flower or the same plant and this happens when a flower has male and female gametes on the opposite cross pollination happens when dust grains are moved to a blossom from another plant. The procedure of cross fertilization occurs with the assistance of abiotic or biotic operators, for example, creepy crawlies, winged creatures, snails, bats and different creatures as pollinators. Abiotic fertilization is a procedure where the fertilization occurs without contribution of outside specialists. The procedure of fertilization which requires outside pollinators is known as Biotic Pollination to move the dust from the anther to the shame. Bugs assume most imperative part as the pollinators. Creepy crawly Pollination happens in plants with shaded petals a solid scent which pulls in honey bees, moths, scarabs, wasps, ants and butterflies. The bugs are pulled into blossoms because of accessibility of nectar, consumable dust and when creepy crawly sits on the bloom, the dust grains adhere to the body. At the point when the bug visits another blossom, the dust is exchanged to disgrace encouraging fertilization. The fertilization is additionally encouraged by vertebrates like feathered creatures and bats. Blossoms pollinated by bats for the most part have white shaded petals and solid smell. The winged animals more often than not fertilize blooms with red petals and without smell (Balasubramani and Marcus, 2014).

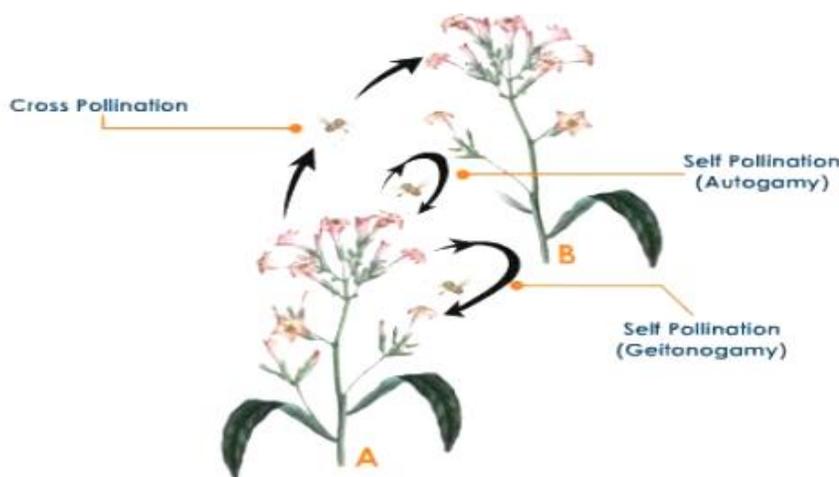


Figure 3.Fertilization

4.2.2 *Flower Pollination Algorithm:* Blooming plants stream preparations get ready impelled Xin-She Yang to make Flower Pollination Algorithm (FPA) in 2012. For facilitate, the four guidelines given are utilized (Yang, 2013).

1. The procedures of worldwide fertilization incorporate Biotic and cross-fertilization, and pollinators passing on tidy move in a way that asserts to Lévy flights.
2. Abiotic and self-pollination are used in local pollination.
3. Blossom steadiness can be considered as the generation likelihood is relative to the comparability of two blooms included.
4. Neighborhood fertilization and worldwide fertilization are controlled by switch probability p which has a value between 0 and 1.

Because of the physical closeness and different variables, for example, wind, nearby fertilization can have a critical part p in the general fertilization exercises. Clearly, in reality, every plant can have different blossoms, and every bloom fix regularly discharge millions and even billions of dust gametes. In any case, for simplicity, we likewise expect that every x plant just has one blossom, and every bloom just create one dust gamete. Along these lines, there is no compelling reason to recognize a dust gamete, a blossom, a plant or answer for an issue. This straightforwardness implies an answer x_i is identical to a bloom as well as a dust gamete. We can undoubtedly stretch out to different dust gametes for every bloom and numerous blossoms for multi target streamlining issues in future reviews.

From the above examinations, we can plan a blossom in view of calculation, specifically, bloom fertilization calculation (FPA). There are two key strides in this calculation; they are worldwide fertilization and nearby fertilization. In the worldwide fertilization step, blossom dusts are conveyed by pollinators for instance, bugs, and tidies can go over a long detachment since dreadful little creatures can consistently fly and move in an anymore drawn out range. This ensures the fertilization and multiplication of the fittest, and accordingly we speak to the fittest as g^* . The main control in addition to bloom steadiness can be formulated as

$$x_i^{t+1} = x_i^t + L(x_i^t - g^*), \quad (11)$$

where x_i^t is the dust i or arrangement vector x_i at cycle t , and g^* is the present best arrangement found among all arrangements at the present era/emphasis. The parameter L is the nature of the preparation, which fundamentally is a phase evaluate. Since dreadful

little animals may move over a long partition with various division steps, we can use a Levy flight to duplicate this trademark productively. That is, we draw $L > 0$ from a Levy conveyance

$$L \sim \frac{\lambda \Gamma(\lambda) \sin(\frac{\pi \lambda}{2})}{\pi} \frac{1}{s^{1+\lambda}} (s \gg s_0 > 0) \tag{12}$$

where $\Gamma(\lambda)$ is the mathematical gamma function, and this formulation is available only in high values of steps $s > 0$. In all our simulations below, we have utilized $\lambda = 1.5$. The neighborhood fertilization (Rule 2) and bloom consistency can be formulated as

$$x_i^{t+1} = x_i^t + \epsilon (x_j^t - x_k^t) \tag{13}$$

where x_j^t and x_k^t are dusted from the diverse blossoms of a similar plant animal variety. Scientifically, if x_j^t and x_k^t originates from comparable species or browsed a comparable masses, this transform into an area discretionary stroll if we draw ϵ from a uniform conveyance in $[0, 1]$. Most blossom fertilization exercises can occur at both nearby and worldwide scale. By and by, adjoining blossom fixes or blooms in the not really far-away neighborhood will probably be pollinated by nearby blossom dusts that those distant. For this, we utilize a switch likelihood (Rule 4) or closeness likelihood p to switch between regular worldwide fertilization to escalate nearby fertilization. Regardless, we can use $p = 0.5$ at first regard and a while later do a parametric survey to find the most fitting parameter extend. From our reenactments, we found that $p = 0.8$ works better for general applications.

5. Simulation Model

The examined approaches have been tried by utilizing IEEE-30 bus system as appeared in Figure 4 which comprises of 4 transformers, 6 generators, 41 lines, and two shunt reactors. The aggregate control variables are 16: six unit dynamic power yields, six generator transport voltage sizes, and four transformers tap settings. All generator dynamic power, and generator transport voltages and transformer tap setting are considered as continuous for straightforwardness. The generators cost coefficients of the IEEE 30-test system are given in the Table 1. The limits of variables of the model are given in Table 2 (Test Case Archive).

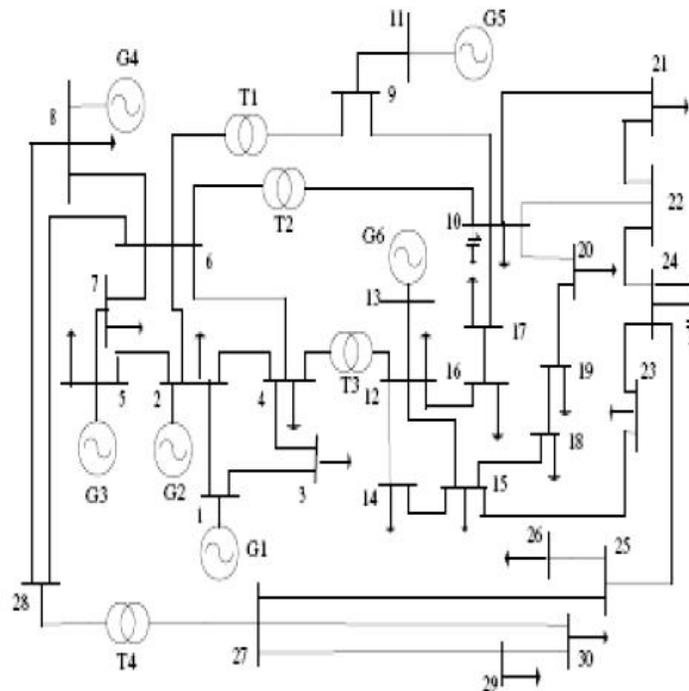


Figure 4. IEEE 30-Bus System

Table 1.Generator cost coefficient of IEEE 30 Bus system

Bus No.	Real Power Output Limit (MW)		Cost Coefficients		
	Min	Max			
1	50	200	0	2.00	0.00375
2	20	80	0	1.75	0.01750
5	15	50	0	1.00	0.06250
8	10	35	0	3.25	0.00834
11	10	30	0	3.00	0.02500
13	12	40	0	3.00	0.02500

Table 2.Limits of Variables for IEEE 30-Bus System

No	Description	Units	Lower Limits	Upper Limits
1	Voltage PQ bus	Pu	0.95	1.05
2	Voltage PV bus	Pu	0.9	1.1
3	Transformer Taps	Pu	0.9	1.1

6. Results and Discussion

The 30 bus IEEE model is tried to check the adequacy of the previous techniques. Both with/without applying the possibility examination were tested for checking the system security at each case. The considered techniques are contrasted and different strategies, with respect to quality and examination adequacy. MATLAB language is used.

6.1. Consequences of a genetic algorithm

Genetic procedure has been tried on the standard model on two steps, initially the contingencies are not considered and the GA based calculation was connected to locate the ideal scheduling of the power system for the base condition. Minimization of the fuel cost is a must. Generator dynamic power and generator bus voltage were taken as an improved components, were taken as improvement components; besides the GA for handling SCOPF problem is attempted. The perfect estimations of control variables procured are given in Table 3.

Table 3.Results of genetic algorithm

	Without line outage (base case)	With line outage (4-6)	With line outage (2-6)	With line outage (1-2)	With line outage (1-3)	Loss of generator
P_1	176.6374	172.6048	172.8813	151.3525	168.4838	188.5079
P_2	48.7022	48.4625	47.6091	59.2858	49.4219	51.6303
P_5	21.6967	21.2781	22.4618	24.0334	21.7093	0
P_8	21.5941	25.4855	25.6042	33.9226	27.5947	27.2177
P_{11}	11.9399	13.3780	12.8147	16.1131	14.5627	14.0737
P_{13}	12.1910	12.1629	12.0940	15.0079	13.8633	13.0268
Gen.Cost \$/hr	801.8566	806.7550	805.9622	839.2858	815.21	832.3776
Loss	9.3613	9.3883	10.0650	16.3153	12.2356	11.0565

6.2. Results of FPA Algorithm

The recently proposed FPA is applied to IEEE 30 bus system for both with/without performing the contingency analysis.

Scenario 1: Optimization without considering any contingency states

This situation is recommended to exhibit the change of the execution of the standard FPA by giving a subjective and quantitative examination in light of the alteration of the control parameters of the standard FPA without any contingency. This case is considered a base case and also optimized to minimize the standard fuel cost.

Scenario 2: Optimization considering different contingencies

In this second situation and so as to demonstrate the effect of different cases on the result, line outages at several locations and loss of generator cases are considered.

The results are shown in Table 4

Table 4. Optimal Results of FPA algorithm

	Without line outage (base case)	With line outage (4-6)	With line outage (2-6)	With line outage 1-2	With line outage 1-3	Loss of generator
P_1	176.7294	172.9495	173.7989	151.1886	168.8781	187.9427
P_2	48.8300	48.4100	47.6720	59.2040	49.1360	51.7400
P_5	21.4750	21.6115	21.4540	24.0580	21.8775	0
P_8	21.6475	25.6100	25.0825	33.9500	27.6750	27.4925
P_{11}	12.0940	13.1700	13.3280	16.3840	14.3140	14.0940
P_{13}	12.0000	12.0000	12.2296	14.8980	13.9236	13.1480
Gen.Cost \$/hr	801.8436	806.7213	805.8811	839.2833	815.1970	832.3756
Loss	9.3753	10.3510	10.1650	16.2826	12.4042	11.0172

From Table 4, we can see that the best cost is achieved by a number of progressive trials, the best aggregate cost accomplished is 801.8436\$/h in the base case. To get the best solutions, a medium number of iterations should be done. With the end goal of checking the effectiveness of the discussed technique, we made a correlation of our calculation with others contending OPF calculations. Table 5 demonstrates the best results of various techniques. Test of factual outcomes is given to demonstrate the capacity of the proposed procedure to accomplish the neighborhood look undertaking. By modifying the cutoff points of control factors amid trials, this permits the lessening of the number of cycles and decreases the execution time, the best aggregate fuel cost discovered considering the base case is 801.8436, and this esteem is exceptionally focused and superior to anything different strategies referred to in countless papers.

Table 5. Comparison of total cost (without line outage)

Power output (MW)	GA	FPA	GA (Banu and Devaraj, 2009)	DE (Priyadarshini and Babu, 2013)	BAT (Sakthivel et al., 2013)	IPSO (Vahedi. et al., 2010)
P_1	176.6374	176.7294	173.6	175.7754	176.27888	198.69
P_2	48.7022	48.8300	50.2	49.1716	49.0012	36.16
P_5	21.6967	21.4750	21.8	21.7542	21.3870	17.64
P_8	21.5941	21.6475	23.8	21.9092	22.4669	11.45
P_{11}	11.9399	12.0940	10.8	12.2328	12.2314	12.15
P_{13}	12.1910	12.0000	12.3	12.1140	11.5256	11.87
Gen.Cost \$/hr	801.8566	801.8436	802.32	802.7683	802.3919	827.13
Loss	9.3613	9.3753	-	9.5572	9.49098	9.12

Table 6 shows the comparison between the proposed algorithm with other recent algorithms in contingency cases with the same fitness function and control variables

Table 6. Comparison of SCOPF results (considering contingency cases)

Approach	Line outage	cost	Losses
Genetic	2-6	805.962	10.0650
FPA		805.8811	10.1650
Differential evolution (Priyadarshini and babu, 2013)		807.8546	10.8358
Genetic	1-2	839.2858	16.3153
FPA		839.2833	16.2826
MI-BFA (Vahedi. et al., 2010)		878.24	-
Genetic algorithm	1-3	815.21	12.2356
FPA		815.1970	12.4042
BPSO (Polprasert et al., 2014)		1217.6	-

From the above results, we can summarize that:

- The meeting qualities of the FPA still require an expansive number of steps to accomplish the best solution.
- A relative review in term of arrangement quality is delineated in Tables 5 and 6, as should be obvious; the examined technique gives preferred outcomes over different late standard and hybrid strategies.
- Each system has its own particular points of interest and disadvantages, in all actuality it relies on upon the capacities, the picked steps, parameters and number of trials.

The test comes about on the IEEE 30-bus model show that the examined SCOPF strategies can discover preferred arrangements over alternate techniques in a speedier merging.

7. Conclusion

In this paper, an effective FPA algorithm has been introduced, adapted and successfully applied to improve the solution of security constrained optimal power flow considering critical objective function. The main contribution of the discussed methodology is minimizing the total generation cost as well as enhancing transmission security and bus voltage profile under typical or unexpected states. The performance of the introduced FPA has been tested with a standard test power system, IEEE 30 bus. It is observed that the proposed approach is capable to reduce the total fuel cost at normal and critical states compared to the old methods.

Nomenclature

SCOPF security constrained optimal power flow
 FPA flower pollination algorithm
 OPF optimal powerflow

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