

A Novel Hybrid Symbiotic Organism Search for Solving Generator Maintenance Scheduling in a Power System

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Abstract

The generator maintenance scheduling (GMS) problem is a high-dimensional complex constrained non linear optimization problem that determines the schedule for carrying out planned preventive maintenance on generating units in a power system. Here, GMS is modelled from the perspective of vertically integrated utility system subject to different set system and operational constraints. Over the last few decades, a number of solution techniques, including nature inspired algorithms, have been developed and proposed to solve this problem. In this paper, a new nature inspired algorithm; symbiotic organism search is proposed to solve the generator maintenance scheduling problem. To examine the efficiency of the proposed algorithm, two test systems, 4-units and 22-units system are considered. The simulation results are compared with that of other existing algorithms, which reveal that the proposed method has merit in terms of solution quality.

Index terms— generator maintenance scheduling, hybrid symbiotic organism search, overall operational cost minimization, optimal generator maintenance schedule.
-Fitness function to be minimized

1 I. Introduction

he generator maintenance scheduling problem is a large scale, stochastic, nonlinear combinatorial optimization problem which is a sub problem of integrated long term operations planning problem. The objective of the GMS problem is to find the exact time interval for preventive maintenance of power generating units with the intention of minimizing the operating cost, maximizing the system reliability and extending the life time of it. In earlier literature, mathematical approaches have been used for solving GMS [1,2,3]. These methods are limited to small size systems having few numbers of generators. For the case of large size systems, the number of intermediate solutions exponentially increases known as curse of dimensionality that restricts the use of mathematical methods to solve GMS. Local search methods such as Simulated annealing (SA) [4], Tabu search (TS) algorithm [5] has been proposed for the solution of GMS problem. For obtaining timetable for the purpose of maintenance of generators, nature inspired algorithms like Particle swarm optimization (PSO) [6], Artificial bee colony (ABC) algorithm [7], Ant colony optimization (ACO) [8], Shuffled frog leaping algorithm (SFLA) [9] have been used. Evolutionary algorithms such as Genetic algorithm (GA) [10], Evolutionary programming (EP) [11], Differential evolution (DE) [12] The generator maintenance scheduling (GMS) problem is a high-dimensional complex constrained non linear optimization problem that determines the schedule for carrying out planned preventive maintenance on generating units in a power system. Here, GMS is modelled from the perspective of vertically integrated utility system subject to different set of system and operational constraints. Over the last few decades, a number of solution techniques, including nature inspired algorithms, have been developed and proposed to solve this problem. In this paper, a new nature inspired algorithm; symbiotic organism search is proposed to solve the generator maintenance scheduling problem. To examine the efficiency of the proposed algorithm, two test systems, 4-units and 22-units system are considered. The simulation results are compared

44 with that of other existing algorithms, which reveal that the proposed method has merit in terms of solution
 45 quality.

46 and other meta heuristic approaches such as Harmony Search (HS) [13], Teaching Learning Based Optimization
 47 (TLBO) [14] have also been applied for the solution of GMS.

48 In this paper, to solve the GMS problem, a new nature inspired algorithm; Symbiotic Organism Search (SOS)
 49 [15] is proposed. To get exact production cost that is to be spent by generating company to meet the weekly
 50 active peak load demand, Lagrange multiplier method (LMM) is hybridized with SOS, which helps SOS in
 51 finding minimum production cost based maintenance schedule for GMS. To examine the efficacy of the proposed
 52 approach, a small size system having 4 generating units and a medium size system having 22 generating units are
 53 considered and simulation results are compared with that obtained using well admired techniques such as PSO
 54 and TS.

55 The paper is organized as follows. In section 2, GMS problem formulation is discussed. Section 3 presents
 56 the detailed explanation of proposed SOS for solving GMS. The simulation results and discussions of using the
 57 proposed technique to solve GMS for 4-and 22-units system are included in Sections 4. Section 5 ends with the
 58 concluding remarks and future scope of the work.

59 2 II. GMS Problem Formulation

60 The cost objective considered here is to minimize the overall operational cost over a planning horizon is stated
 61 as
$$C_{total} = C_{production} + C_{maintenance} \quad (1)$$

62 The first part of (1) is production cost and second part signifies the variable operation and maintenance cost.
 63 The fixed maintenance cost is constant and does not have influence on maintenance schedule and hence it is
 64 neglected in the formulation.

65 The solution obtained for the GMS problem must satisfy the following set of system and operational
 66 constraints.
$$P_{i,t} \leq P_{i,max} \quad (2)$$

67
$$P_{i,t} \geq P_{i,min} \quad (3)$$

68
$$P_{i,t} \leq P_{i,max} \quad (4)$$

69 The constraint (2) is the maintenance window constraint which ensures that once maintenance of the unit
 70 i begins, the work have to be continued without any break off for the time period that is exactly equal to
 71 maintenance duration of unit i . To ensure no two generators is maintained by same crew, it is stated in terms
 72 of U it variables of second unit $i2$ as in (3). Crew constraint restricts maintenance of unit 1 and 2 in unison. In
 73 some situation, the maintenance works on some of the power producing units should be initiated only after the
 74 completion of maintenance activities of other generators. This can be achieved with the inclusion of precedence
 75 constraint. For instance, if maintenance of unit '2' is to be started only after the completion of maintenance of
 76 unit '1', then this constraint is given by (??). In every sub-period of planning horizon, the sum of capacity of
 77 generating units that are switched off for maintenance must be lesser than gross reserve in that sub-period. This
 78 can be achieved by using resource constraint as given in (5). Constraint (6) guarantees the real power output
 79 from every generator is within its minimum and maximum limits. Load balance constraint is given by (7).

80 3 III. Proposed Solution Methodology

81 The GMS problem have two types of variables; continuous and binary integer variables. The continuous variables
 82 denote the power output from the online generating units and binary integer variables indicates the on/off status
 83 of power producing units. Here, as in most of the literature, the starting period for maintenance of each generator
 84 is considered as variables which are integers. The number of integer variables is exactly equal to number of
 85 generators present in the system. To solve the problem, symbiotic organism search (SOS) a population based
 86 new meta-heuristic nature inspired algorithm is proposed. The SOS is initially developed by Cheng and Prayogo
 87 in 2014 [15]. Basically SOS has been proposed for solving the problem in continuous domain. This algorithm
 88 requires only common control parameter such as population size and maximum number of generations to be
 89 tuned and does not have any algorithm specific control parameters. It mimics the symbiotic interaction strategies
 90 adopted by two organisms to stay alive and propagate in the ecosystem. To evolve to a good solution, SOS uses
 91 three important phases; mutualism, commensalism and parasitism. The flowchart of the SOS is shown in Fig.
 92 ??.

93 4 Fig. 1: Flowchart of Symbiotic Organism Search

94 To deal with integers, a rounding off operator is used in SOS called integer coded symbiotic organism search
 95 (ICSOS). The detailed explanation of proposed solution methodology for solving GMS problem is given below.

96 5 a) Hybrid SOS for Cost based GMS

97 The cost objective is given in (1). The aim is to obtain a maintenance schedule for the GMS problem such that
 98 the overall operation cost should be minimized. To obtain the exact production cost involved to meet the weekly
 99 peak load demand, a LMM is hybridized with ICSOS called hybrid SOS (HSOS). The following are the steps
 100 involved in HSOS for solving cost based GMS.

101 i. Initialization Initialize NP population called ecosystem. Each vector of ecosystem called organism represents
 102 one candidate solution of the problem. Each organism (X k) has integers decision variables equal to number
 103 of generators present in the system which is generated randomly between every generator's earliest and latest
 104 allowed starting period for maintenance as follows () () () () k E i k L i k E i k i S S random S round X ? + = .
 105 1 , 0(8)

106 The integer variables are checked for precedence and crew constraints. If any of the above constraint is violated
 107 for a particular generator, the corresponding integer variable is chosen randomly until the constraints are satisfied
 108 and then the integer variables are checked for maintenance window constraint. After satisfying all the constraints,
 109 the status of each unit is set at '0' from the starting period up to its corresponding maintenance duration period
 110 to indicate that the unit i is switched off for preventive maintenance and '1' during other periods. The LMM is
 111 used to achieve optimal generation schedule from the online generators in every week to meet the weekly load
 112 demand as follows.

113 Step 1: With initial value of ?, power output from each committed generator (P i) in sub-period t can be
 114 calculated using $P_i = P_{i,t} + \Delta P_i$ (9)

115 The generated output power is checked to satisfy constraint (6).

116 Step 2: The change in power output (ΔP) can be calculated using Step 3: The change in ? (??) can be found
 117 as follows

118 6 No

119 $\Delta P = \Delta P_{i,t} + \Delta P_{i,t+1}$ (11)

120 Step 4: The new value of ? for the next iteration (K+1) can be found by adding change in ? with previous
 121 value of ? as follows $P_{i,t+1} = P_{i,t} + \Delta P_{i,t+1}$ (12)

122 The above steps are repeated until ΔP becomes zero. Thus constraint (7) is satisfied. The fitness function of
 123 the GMS problem to be minimized by HSOS is $F = \sum_{i=1}^n C_i P_i + \sum_{i=1}^n T_i \Delta P_i + \sum_{i=1}^n N_i \Delta P_i + \sum_{i=1}^n C_i V_i$
 124 $C_i P_i + H_i \Delta P_i + \dots$ (13)

125 ii. Mutualism Phase In mutualism phase, two participating organisms of the ecosystem get benefited. In SOS,
 126 two organisms X y and X z are selected. They interact each other with the aim of increasing mutual survival
 127 advantage in the ecosystem. The new solution after mutual relationship is given by $(X_y, X_z) = (X_y + \Delta X_y, X_z + \Delta X_z)$
 128 $\Delta X_y = \Delta X_z = \Delta X$ (14) $(X_y, X_z) = (X_y + \Delta X_y, X_z + \Delta X_z)$ (15)
 129 where X best is the best organism in the ecosystem which is used in SOS to model the highest degree of
 130 adaptation, that is the objective of both organisms. After creating the starting period for maintenance of each
 131 generator using equations (??4) and (??5) they are checked for any constraints violation. If all the constraints
 132 are satisfied, the status of each unit is set at '0' from the starting period up to its corresponding maintenance
 133 duration period to indicate that the unit i is taken out for preventive overhauling work and '1' during other
 134 periods. The minimum production cost for new organisms that denotes the starting period for maintenance of
 135 thermal units is calculated with the help of LMM. The fitness function is calculated for new organisms using
 136 equation (13). If these organisms have better fitness, the current organism is replaced by the new one.

137
 138 iii. Commensalism Phase During this phase, an organism X y gets benefited by interacting with randomly
 139 generated another organism X z in the ecosystem. But X z is neither suffered nor benefited. A new solution
 140 of X y is determined based on the commensalism operation among the organisms X y and X z , which can be
 141 expressed as $(X_y, X_z) = (X_y + \Delta X_y, X_z)$ (16)

142 Once the new organism that indicates the starting period for maintenance of power generating units is
 143 determined, it is checked in order to satisfy constraints (2) - (5). After satisfying all the constraints, the status
 144 of each unit is set at '0' from the starting period up to its corresponding maintenance duration period to indicate
 145 that the unit i is taken out for planned preventive maintenance and '1' during other periods.

146 Then LMM is used to obtain optimum generation schedule from the online generators in every sub-period to
 147 meet the weekly peak load demand with minimum production cost. The fitness function is calculated for new
 148 organisms using equation (13). The new organism X y,new is accepted, if it has better fitness, than the current
 149 organism.

150 iv. Parasitism Phase In this phase, a parasite vector X y,new is created in the search space by duplicating
 151 organism X y and its dimensions are perturbed using a random number as follows $(X_y, X_z) = (X_y + \Delta X_y, X_z)$
 152 $\Delta X_y = \Delta X_y \cdot r$ (17)

153 The parasite vector that indicates the starting period for maintenance of generating units is checked in order
 154 to satisfy constraints (2) - (5). After satisfying all the constraints, the status of each unit is set at '0' from the
 155 starting period up to its corresponding maintenance duration period to indicate that the unit i is taken offline for
 156 maintenance and '1' during other periods. Then LMM is used to obtain optimum generation schedule from the
 157 online generators in every sub-period to meet the weekly peak load demand with minimum production cost thus
 158 satisfying generator limit and load balance constraints given by equations (??) and (7). The fitness function is
 159 calculated for new organisms using equation (13). An organism X z is chosen randomly from the ecosystem that
 160 serves as a host for the parasite vector X y,new . If the parasite vector has better fitness function value, then
 161 it occupies the space of its corresponding host by killing them. The above phases are repeated until maximum
 162 number of generations.

7 IV. Simulation Results and Discussions

In order to prove the superiority of the proposed HSOS algorithm, two test systems; one is small system having 4 generators and another one is medium size system having 22 power generating units are considered [5,12]. In the proposed approach, Lagrange Multiplier method is hybridized with ICSOS in order to solve large scale generator maintenance scheduling problem. In HSOS approach, ICSOS tries to find an optimal starting period for maintenance of power generating units with the help of LMM which tries to economically dispatch the available generation from committed generators to meet the weekly peak active load demand with minimum production cost. The program is developed using MATLAB on a personal computer with 3 GHz core i5 CPU. The simulation results are compared with that achieved via particle swarm optimization scheme.

8 a) Test System 1: 4 Units System

There are 4 thermal generating units to be maintained within a planning period of 8 weeks. Among 4 generating units, due to precedence constraint, the maintenance of unit 1 must be completed before the starting of maintenance of unit 2. Due to crew constraint, units 1 and 2 should not be under maintenance simultaneously. The generator data is given in [12]. The gross reserve in every week can be calculated by taking difference between installed capacity and load demand in that week. The weekly peak load data is given in Table 1. In order to compare the results of proposed HSOS and mathematical approach assisted particle swarm optimization (MAPSO) [12], the population size and maximum number of generations for both the algorithms are set at 10 and 500 respectively. Since the test system 1 is a small system, both the algorithms produce the same maintenance schedule. Table ?? shows the maintenance schedule of 4 units system. Here, '0' indicates the unit is taken out for maintenance and '1' indicates that the unit is available to serve the load. From the table, it can be seen that unit 1 and 2 are not under maintenance in unison, thereby satisfying crew constraints. Also, the maintenance of unit 2 begins only after the completion of maintenance of unit 1, thereby satisfying precedence constraint. In Table ??, it is clear that each generator is under maintenance only once during the planning period and is equal to corresponding maintenance duration week, thereby satisfying maintenance window constraint.

9 Table 2: Maintenance Schedule of 4 Units System

Unit/Week 1 2 3 4 5 6 7 8 1 1 1 0 0 0 0 1 1 2 1 1 1 1 1 1 0 0 3 0 0 1 1 1 1 1 1 4 1 1 1 1 1 1 0 1

Fig. ?? shows the capacity on maintenance in every week. From the figure, it can be seen that, in every week, the capacity of units that are taken out for maintenance is lesser than the gross reserve in that week, thereby satisfying resource constraint.

10 Fig. 2: Capacity on Maintenance

Table 3 shows the power output from online generators obtained using LMM. From the table, it can be seen that power output from committed generators are within their lower and upper bounds, thereby satisfying generator limit constraint. The sum of the power output from available generators in every week is exactly equal to corresponding active power load demand, thus satisfying load balance constraint. For the maintenance schedule of 4 unit system that is obtained through Tabu Search (TS) algorithm [5], the authors have not given the overall production cost. For the same schedule, using LMM the overall operation cost is found. Table 4 shows the comparison of overall operational cost between proposed method with other existing methods. The available reserve in every week can be calculated by taking difference between installed capacity and sum of capacity on maintenance and weekly load demand. The minimum reserve obtained for the above maintenance schedule is 225 MW in 2 nd week.

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12 b) Test System 2: 22 Units System

In this system, there are 22 generating units that have to be maintained once within a planning horizon of one year. The planning period is divided into 52 subperiods (weeks). The generator data is provided in [12]. The weekly load data is given in Fig. ??.

13 Fig. 3: Load Data of 22 units system

Due to precedence constraint, units 2 and 5 should be taken out for maintenance before the commencement of maintenance of units 3 and 6 respectively. Due to crew constraints, units 15 and 16, units 21 and 22 should not be under maintenance at the same time.

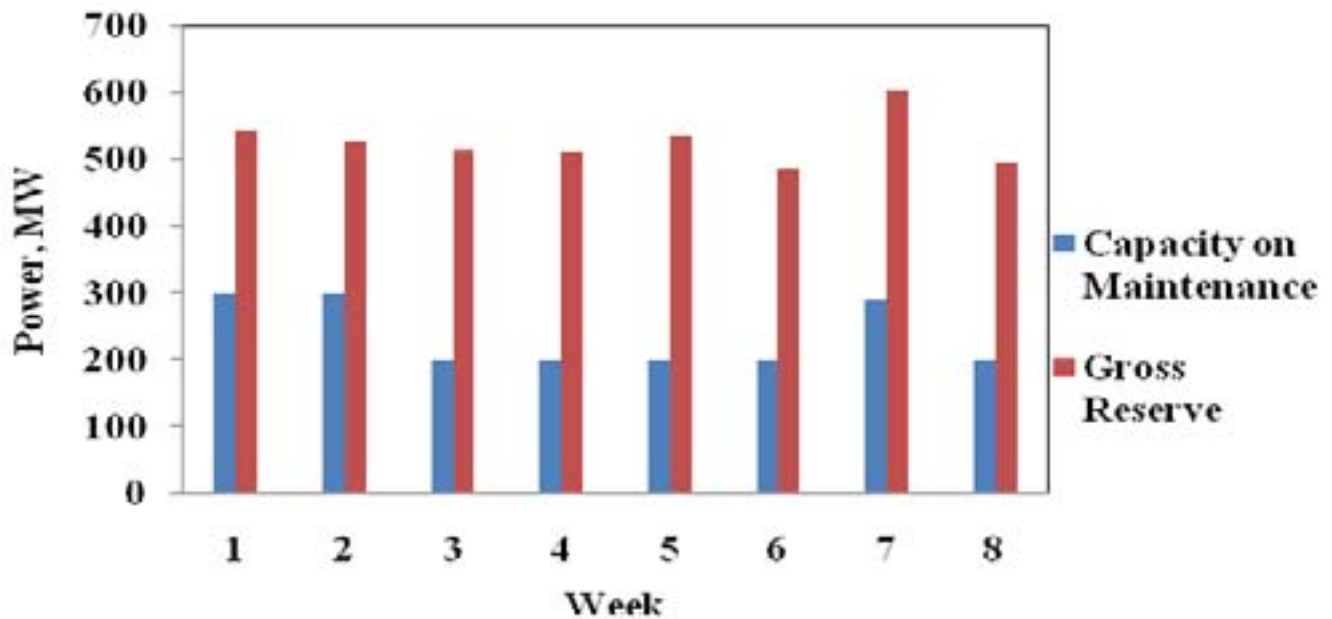
To make the comparison between proposed HSOS and MAPSO, population size and maximum number of iterations are fixed at 50 and 2500 respectively. The convergence characteristics of 22 units system is shown in Fig. 4. From the characteristics, it can be seen that though HSOS have speed of convergence lower than MAPSO, it produces better maintenance schedule in terms of overall operational cost which includes production as well as variable operation and maintenance costs than MAPSO. Table ?? and 6 shows the maintenance schedule obtained through proposed HSOS algorithm and MAPSO. From Table 5 and 6, it can be seen that in both the schedules,

218 each unit is taken out for maintenance only once during the planning horizon and is under maintenance without
 219 any interruption for the period equal to corresponding maintenance duration weeks. Thus, the maintenance
 220 window constraint gets satisfied. The gross reserve in every week is given in [5]. In every week, the capacity
 221 on maintenance is lesser than the gross reserve in that week. Thus resource constraint is satisfied. In Table ??
 222 and 6, it is evident that the maintenance on units 2 and 5 gets completed before the starting of maintenance on
 223 units 3 and 6 respectively satisfying precedence constraint. Also units 15 and 16, units 21 and 22 are not under
 224 maintenance in same duration satisfying crew constraint.

225 The comparison of overall operational cost for 22 units system satisfying generator limit and load balance
 226 constraints are given Table 7.

227 14 V. Conclusion

228 A new nature inspired algorithm for the optimization of generator maintenance scheduling problem in vertically
 229 integrated system is presented in this paper. In the proposed approach, conventional lambda iteration approach or
 230 Lagrange Multiplier method is hybridized with integer coded symbiotic organism search algorithm. The lambda
 231 iteration approach assists symbiotic organism search algorithm in finding optimal starting period for maintenance
 232 of generating units. The proposed approach provides a feasible maintenance schedule for the generating units by
 233 considering minimization of overall generator operation cost as objective which includes production and variable
 234 operation and maintenance cost while satisfying system and operational constraints. The proposed method is
 235 validated by considering two test systems. The superiority of the proposed HSOS algorithm is demonstrated
 236 by comparing the results with the results obtained from MAPSO algorithm. The results conclude that both
 237 HSOS and MAPSO are well suited for solving generator maintenance scheduling of small system. For solving
 238 large scale generator maintenance scheduling problem, HSOS outperforms MAPSO in terms of finding the overall
 239 generation operation cost. Thus, test results reveal the capability of the proposed algorithm in finding the optimal
 240 solution for the GMS problem. The proposed approach can be extended for the solution of GMS problem in the
 competitive environment without any difficulty.¹



4

Figure 1: Fig. 4 :

241

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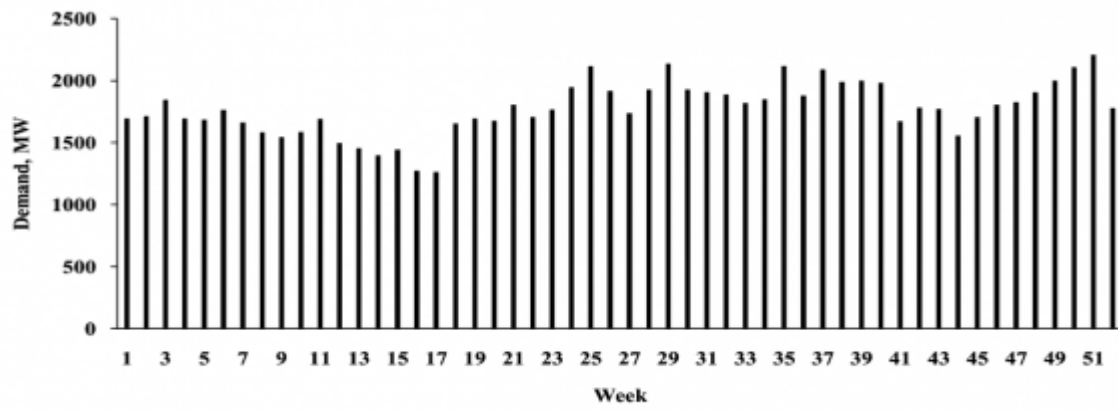


Figure 2:

Keywords: generator maintenance scheduling, hybrid symbiotic organism search, overall operational cost ?

minimization, optimal generator maintenance schedule.

Nomenclature

i	-Power generating unit index
I	-Total number of generating units
t	-Time period index (week)
T	-Total number of sub periods (weeks) in the planning horizon
nc	-Constraint index
NC	-Total number of constraints
k	-Population index
K	-Iteration index in La-

		830	10,15
19	1695	460	15,22
20	1675	560	12,15,22
21	1805	440	3,12,22
22	1705	440	3,12,22
23	1766	440	3,12,22
24	1946	100	12
25	2116	100	12
26	1916	320	12,20
27	1737	320	12,20
28	1927	220	20
29	2137	0	—
30	1927	0	—
31	1907	220	16
32	1888	220	16
33	1818	220	16
34	1848	220	16
35	2118	220	16
36	1879	220	16
37	2089	0	—
38	1989	0	—
39	1999	0	—
40	1982	0	—
41	1672	650	9
42	1782	650	9
43	1772	650	9
44	1556	650	9
45	1706	650	9
46	1806	90	6
47	1826	90	6
48	1906	90	6
49	1999	90	6
50	2109	0	—
51	2209	0	—
52	1779	0	—
Weeks Load Maintenance Capacity Units on Maintenance			
1	1694	511	8,11,15,17
2	1714	511	8,11,15,17
3	1844	511	8,11,15,17
4	1694	511	8,11,15,17
5	1684	320	15,17
6	1763	610	10
7	1663	610	10
8	1583	610	10
9	1543	610	10
10	1586	610	10
11	1690	610	10
12	1496	710	10,14
13	1456	950	10,14,21
14	1396	950	10,14,21
15	1443	950	10,14,21
16	1273	1350	4,10,12,13,14,18,22

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