Congestion Management in Interconnected Power System using Water Cycle Algorithm

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ABSTRACT

Nowadays, it is desirable for the power industry to transmit power between different sites of the transmission system in the most cost-effective manner. Congestion management is one of the system operator's most challenging responsibilities in a deregulated context. Congestion would increase electricity costs and transmission loss and have a negative impact on the system's stability and security, so system operators work on it to reduce congestion in deregulated power systems. In this investigation, congestion is handled by considering three objective functions. The first objective is to minimize the generation cost and the second objective is to minimize the transmission loss of the system and third objective is to minimize the total congestion expanse. A water cycle algorithm is employed to mitigate the proposed congestion management and an IEEE 30 bus and 118 bus test system is employed to demonstrate the effectiveness of the suggested approach.

Keywords: Congestion Management, Deregulation, MATLAB, Optimization Technique, Water Cycle Algorithm

LIST OF SYMBOLS

ALO	Ant Lion Optimization
ATC	Available Transfer Capability
CM	Congestion Management
DG	Distribution Generator
DE	Differential Evolution
DTR	Dynamic Thermal Rating
GSO	Glowworm Swarm Optimization
LMP	Location Marginal Price
OPF	Optimal Power Flow
OTS	Optimal Transmission Switching
PSO	Particle Swarm Optimization
RES	Renewable Energy Sources
WCA	Water Cycle Algorithm
F_1	Total Generation Cost
F_2	Transmission Loss
P_{gi}^{*}	Active Power Generation
Q_{gi}^{*}	Reactive Power Generation
V_i	Voltage Magnitude of i buses
V_j	Voltage Magnitude of j buses
P_{gi}^{*max}	Upper limit of the Active Power Generation
P_{gi}^{*min}	Lower limit of the Active Power Generation
Q_{gi}^{*max}	Upper limit of the Active Power Generation
Q_{gi}^{*min}	Lower limit of the reactive power Generation
V_{gi}^{max}	Upper limit of the Voltage Magnitude
V_{gi}^{min}	Lower limit of the Voltage Magnitude

1. INTRODUCTION

With the increase in population, industrialization, and modernization, demand for electricity also increases. The dramatic rise in electrical energy use in recent decades has resulted in a high demand for renewable energy sources, particularly solar [1]. The electrical system is intricately linked. Continuous growth in the electrical power sector strains the transmission capacity and puts the distribution system under stress [2]. The increasing electricity demand compels the electrical power sector to enter a deregulated environment where the main functions of the power sector, i.e., generation, transmission, and distribution, are controlled by different authorities. Now private parties can also enter the power sector. Any organization can now generate and distribute electricity. As a result, competition arises among all the sellers to sell their generated electricity to the consumers. Now every generation company tries to supply their power to consumers using the transmission lines. As a result, the burden on the transmission lines increases, and sometimes the power flow through transmission lines exceeds the flow allowed by the transmission lines, which, if unchecked, can harm the entire power system and cause a total blackout. This severe condition of the transmission lines is known as congestion. Congestion can become terrible if it is not removed from the network immediately. Several transfer constraints, including heat limits, voltage limits, and stability limits, place restrictions on the amount of electric power that can be transmitted via a transmission network between any two points. The system is referred to as "congested" when this limit is reached. In a competitive market, it is the inability of the transmission lines to make up all desired transactions due to system limitations. Reasons behind this kind of violation are sudden stopping of generators, faults or maintenance in transmission lines, sudden

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changes in the load, and uncoordinated transactions.

Transmission companies (TRANSCOs), generation companies (GENCOs), and distribution companies (DISCOs) all fall under one organisation in regulated electricity systems, typically the government. The government will bear all costs associated with the power system, and any revenue generated will also be given to the government. Contrarily, in deregulated power networks, TRANSCOs, GENCOs, and DISCOs are under the control of several entities [3]. Utilities must find a cost-effective transmission technology to fully utilize existing transmission infrastructure because installing new transmission lines to relieve congestion is time- and money-consuming. The transmission network has become more congested as a result of incorporating highly efficient renewable energy, increasing power demand, and ageing transmission infrastructure. Due to the system's inherent flexibility, this necessitates that transmission service providers utilise the current transmission infrastructure to its fullest extent by utilizing affordable new transmission technologies. In general, there are two different kinds of CM approaches that can be found in the literature: non-cost-free methods and cost-free methods. Of the two, the latter way technically reduces congestion, while the former is related to economics. Reference [4] discussed one of the techniques that can aid in congestion control and other transmission operating problems: dynamic thermal rating (DTR), where the combination of DTR and optimal transmission switching (OTS) technologies offers adaptable ways to boost the efficiency of the electrical grid and maximize the best utilisation of the current transmission infrastructure, and this paper uses OTS techniques to demonstrate a stochastic multi-objective congestion control method that maximizes system reliability while minimizing total generation costs. Transmission switching has been investigated as a technique to harness flexibility from existing transmission infrastructure to lower the system operating cost, in addition to acting as a corrective control action or to reduce system loss. Optimal transmission switching (OTS) was first proposed by Fisher et al. [5] while referring to DC optimum power flow (DCOPF). The proposed formulation treats the transmission lines' on/off status as a binary variable. OTS can dramatically lessen system congestion in addition to lowering system running expenses [6]. Transmission switching for congestion control was researched by Granelli et al. [7]. S Charles Raja et al. use the Hybrid Nelder-Mead-Grey Wolf Optimizer (HNMGWO) to reschedule generators in the power system to mitigate congestion at the lowest possible cost.

The proposed HNMGWO was tested in IEEE 30 bus and IEEE 118 bus systems and compared to standard GWO, fuzzy adaptive PSO, a genetic algorithm, and bacterial foraging algorithms [8]. In reference [9], the researcher explained that it is a difficult and complex task to manage congestion in a deregulated electricity system, but it may be done by connecting one or more Distributed Generators (DG) in the best position. The best placement and size of DGs are found by using Transmission Congestion Rent (TCR), Differential Evolution (DE), and Particle Swarm Optimization (PSO) techniques to mitigate the congestion. This study proposes a unique congestion minimization strategy within the OPF methodology, as discussed in reference [10] in relation to reorganised electricity markets. The traditional OPF issue is changed to incorporate a mechanism that allows industry participants to trade and compete while also ensuring the security of the system. The multi-objective glowworm swarm optimization (MO-GSO) technique was employed to address the proposed multi-objective-based CM issue. Reference [11] discussed a multi-objective-based congestion management (CM) methodology where it is suggested to utilise optimal transmission switching (OTS) strategies, taking into account that maximizing probabilistic dependability and minimizing overall operating cost are two competing goals. Reference [12] proposes a technique for assigning a thyristor-controlled series compensator (TCSC) utilizing the congestion cost contribution methodology based on location marginal price, which is based on optimal power flow (OPF) and available transfer capability (ATC). As Farzana, D, et al. suggest about a competitive energy market setting, this research study proposes a framework for controlling the power flows of power lines within the allowed limit by rearranging with and without renewable energy sources (RES). Rearranging the schedule is described as a way to reduce the expense of congestion. Unlike the conventional approach, a novel weighted location marginal price (LMP)-based approach is used to determine the ideal location for the installation of RES. To achieve optimal outcomes, the firefly algorithm (FA) and particle swarm optimization (PSO) method are used [13]. Reference [14] discusses the application of an improved twin extremity chaotic map adaptive particle swarm optimization (TECM-PSO) technique towards the complex congestion management pricing challenge in the unregulated electric grid. The recommended method has two objectives: first, to accurately count the number of generators taking part in the rescheduling procedure using a reliable upstream real capacity tracing method that requires an acute description of generator units; and second, to minimise the cost function of the rescheduled generation while removing all line overloads. Majid Moazzami et al. discussed congestion management mitigation in the restructured power system using FACTS devices to reduce transmission loss and generation cost. So in order to relocate TCSC, the Ant Lion Optimization Algorithm (ALO) was used in the study to perform a congestion management analysis to pinpoint the best place for the placement of TCSC, which is modelled on a 14-bus test system while taking into account the competitive environment's limitations [15]. Kumar Tiwari et al. present a two-step optimization strategy for reducing transmission line congestion in order to maximize system gain, minimize the system price of generation, and reduce the cost of congestion and emissions by strategically placing TCSC near wind generators. They emphasize the use of FACTS devices to deal with congestion management problems and achieve maximum profit with minimized congestion. This paper proposes a suitable method to manage congestion by optimally placing a FACTS device known as the TCSC with a generator running on it. This paper proposed two indexes to determine the most congested lines, the TCSC optimal location, and the number of TCSC devices needed to minimize the congestion. Along with the formulation of the proposed problem, it presented the mathematical model of a static TCSC device, a wind generator, and location marginal pricing.

The proposed approach is then applied to modified IEEE 14-bus and IEEE 118-bus systems by using MATLAB to check whether the proposed method is effective or not. Moreover, the results obtained are compared to an existing congestion management method, which shows a significant reduction in congestion management costs with the proposed method. The effect of TCSC and wind power generators on system profit is also presented, demonstrating that the presence of wind power generators increases system profit while decreasing congestion [16]. Reference [17] proposes a transmission congestion management method using optimal generation rescheduling while taking into consideration issues related to voltage stability. According to this paper, in congestion management, using optimization methods leads to setting the upper or lower bounds of control variables, which can lower the voltage security after optimization. Active power rescheduling combined with reactive power rescheduling and reactive capacitor support is thus proposed to alleviate congestion as well as voltage stability issues. The optimization technique used in this paper is the Random Inertia Weight Particle Swarm Optimization (RANDIW-PSO) algorithm, which was chosen after a comparative study of three other particle swarm optimization methods as it is faster and more accurate than the others.

This paper formulates the congestion management problem, gives a detailed analysis of active and reactive power rescheduling, the optimization technique, the algorithm for the proposed method, and the implementation steps. The proposed method is tested on an IEEE 39 bus system and yields positive results, demonstrating that it can successfully reduce congestion costs by improving voltage stability and system performance. M. Negnevitsky et al. proposed a congestion management method based on rescheduling of generation with the help of modified particle swarm optimization for a deregulated power market along with renewable energy sources. This paper presents a brief description of congestion and its management methods, formulates the congestion management problem, and also describes the modified Particle Swarm Optimization method. It emphasizes congestion management methods by considering system sensitivity and dynamic constraints. The optimization method is implemented in MATLAB software, and this proposed method was tested on an IEEE 8 bus system and the results were successfully analysed, which shows that the proposed method can be successfully applied to mitigate congestion. The proposed method results in a congestion-free power system and successfully obtains optimal rescheduling of power plants by considering their behaviour in turning on and off at different times [18].

2. PROBLEM FORMULATION

The most crucial factor to be considered when building a system to control congestion is effective power transfer at a reasonable cost by minimizing transmission loss. Surender Reddy Salkuti and Seong-Cheol Kim developed a solution to manage congestion. In their work, transmission loss was reduced by implementing a new method based on advanced optimization inspired by nature and the behavior of glowworm swarms [10]. The following are the paper's main contributions:

i. The cost of generation is reduced, and transmission costs are reduced.
ii. On the IEEE 30 bus and IEEE 118, the proposed water cycle algorithm is run and tested.
iii. Congestion cost and congestion are alleviated in IEEE 30bus

Compared to the current method, the findings of this water cycle show that they satisfy both.

2.1 Objective Function

Reducing generation costs and transmission losses is the fundamental objective of the proposed congestion management system in equation (1) [10-11] and equation (2) [14-16] respectively.

$$F_1 = \min \sum_{i=1}^{N_g} C_i\left(P_{gi}^*\right) = \sum_{i=1}^{N_g}\left(a_i + b_i P_{gi}^* + c_i P_{gi}^{*2}\right) \quad (1)$$

$$F_2 = \min\left[\frac{1}{2}\sum_{i,j}\left[g_{ij}\left(V_i^2 + V_j^2 - 2V_iV_j\cos\left(\delta_i - \delta_j\right)\right)\right]\right] \quad (2)$$

$$F_3 = \min\left(\sum_g^{ng} C_{gp}(\Delta P_g).\Delta P_g\right) \quad (3)$$

where, total generation cost is represented as F_1 and the F_2 represents the transmission losses. a_i, b_i, and c_i denotes the cost factors of i^{th} generator, P_{gi}^* is the p.u value of the generation unit which means power generated per unit, g_{ij} is the conductance of the line and V_i, V_j are the bus voltages and δ_i, δ_j are the phase angles of each bus.

The first objective of proposed congestion management problem is to minimize the total cost of generation which can be expressed as a quadratic equation as mentioned in equation (1).

The value of P_{gi}^* is generated in such a way that it meets generation and demand. The optimal dispatching of the generators is done in such a way that the social welfare is maximized while satisfying the operation and security related constraints. The cost obtained in this process comes without considering the market bidding prices. If the bidding prices are being considered the objective function will become congestion rental function.

It is fact that the unit of electric energy generated by power station does not match with the units distributed to the consumers. Some percentage of the units is lost in the distribution network. This difference in the generated & distributed units is known as transmission and distribution loss. Hence the next objective of our congestion management problem is to minimize the transmission line loss which can be calculated as mentioned in equation (2) where, δ_{ij} is the conductance of the admittance matrix formed by using the line data of IEEE bus system. The proposed algorithm generates bus voltage and phase angles randomly and calculates the loss using the above equation. Conductance is obtained from the real part of the admittance matrix and after calculating loss the algorithm efficiently minimizes the loss.

In equation (3) objective, the aim of the function is lowering the total congestion management expense resulting from the rescheduling of real under-constrained operations based on price offers provided by GENCOs. Where F_3 represents the total expense incurred by the system operator to modify the real power generation of the participating generators for the purpose of managing congestion. $C_{gp}(\Delta P_g)$ is the per MW price bid that participating generators submit to alter their generational output in order to control congestion. At those costs, the participating generators are eager to alter their actual power outputs. ΔP_g is the variation from the scheduled value that was announced following the market clearing operation.

3. PROBLEM CONSTRAINTS

3.1 Equality Constraints

The constraints of equality are the essential conditions relating real as well as reactive power in an entire power system that should be satisfied. It also helps in state estimation. The equality constraints are the typical power flow solutions of a power system and are expressed in eqns. (4) and (5) [10-11] as,

$$P_{gi}^{*} - P_{di}^{*} = V_i \sum_{j=1}^{n} V_j \left(E_{ij} \cos \delta_{ij} + F_{ij} \sin \delta_{ij} \right) \quad (4)$$

$$Q_{gi}^{*} - Q_{di}^{*} = V_i \sum_{j=1}^{n} V_j \left(E_{ij} \sin \delta_{ij} - F_{ij} \cos \delta_{ij} \right) \quad (5)$$

where $i = 1, 2, 3, ..., n$ and n represents amount of buses in the power method in eqns. (4) and (5). E_{ij} and F_{ij} are the real as well as imaginary parts in the bus admittance of matrix and they represent mutual conductance also susceptance among the buses correspondingly. V_i and V_j represents the voltage magnitude of i as well as j buses.

3.2 Inequality Constraints

The inequality constraints have been formulated for the diverse components used in the system and detailed as follows:

3.2.1 Generator Constraints

The outputs of the generators in terms of real as well as reactive power are restricted by means of their higher limits and lesser limits. These inequality constraints of the generator unit are expressed in eqns. (6) and (7). [10-11]

$$P_{gi}^{*\min} \leq P_{gi}^{*} \leq P_{gi}^{*\max} \quad (6)$$

where $i = 1, 2, ..., N_g$.

$$Q_{gi}^{*\min} \leq Q_{gi}^{*} \leq Q_{gi}^{*\max} \quad (7)$$

where $i = 1, 2, ..., N_g$.

The bus voltages of generator are limited by the following constraint represented by eqn. (8)

$$V_{gi}^{\min} \leq V_{gi} \leq V_{gi}^{\max} \quad (8)$$

where $i = 1, 2, ..., N_g$.

3.2.2 Constraints of Transformer

Transformer tapings have maximum and minimum restrictions. Restrictions occur in these limits and are expressed in the following eqn. (9) [10-11].

$$T_{n}^{\min} \leq T_n \leq T_{n}^{\max} \quad (9)$$

where $n = 1, 2, ..., N_{TF}$.

3.2.3 Switchable VAR Bases

The bases of switchable VAR has limitations as in eqn. (9)

$$Q_{n}^{\min} \leq Q_n \leq Q_{n}^{\max} \quad (10)$$

where $n = 1, 2, ..., N_{sv}$.

3.2.4 Constraints of Security

The security constraints of the modern power system have been symbolized using eqns. (11) and (12) [10-11] as,

$$V_{Dn}^{\min} \leq V_{Dn} \leq V_{Dn}^{\max} \quad (11)$$

where $n = 1, 2, ..., N_D$.

$$S_{Ln} \leq S_{Ln}^{\max} \quad (12)$$

where $n = 1, 2, ...N_{line}$.

All equality and inequality constraints have been validated in the system design of buses.

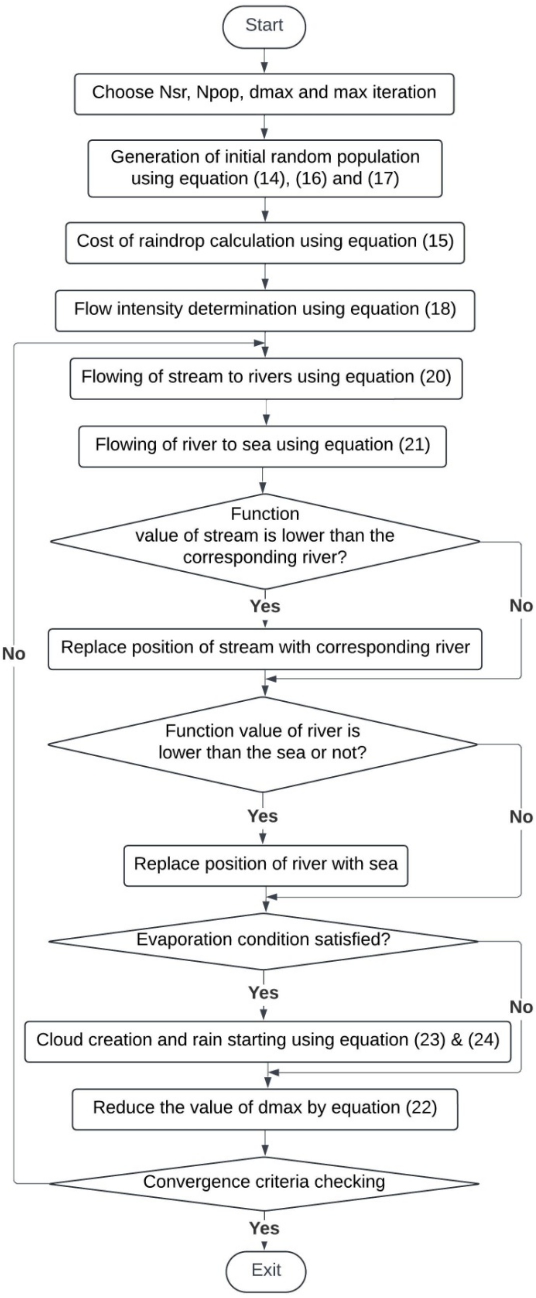

***Fig. 1**: Flow Chart for WCA.*

4. WATER CYCLE ALGORITHM

4.1 Basic Concepts

Nature is the inspiration behind this WCA method. It necessitates understanding of the water cycle and the flow of streams and rivers to the sea. Water moving from upper places to lower ones ultimately forms a stream or river. Most high mountains are the starting point of a river due to the melting of snow, and glaciers and oceans are the ending point where the collection of all the water is done.

As per the water cycle, evaporated water from various sources creates clouds, which, after condensation, reach back to earth in the form of rain. Water from rain and glaciers goes into the aquifer, which is then released into a lake or river. Water then evaporates again, completing the cycle. Water from rain is collected in streams and a river, which finally goes into the sea. This method initially generates the raindrops as a population. The sea is thought to have the best raindrops. Good raindrops are rivers, while the rest are streams that flow to rivers and the sea [19].Create the initial population. Problem variables are taken as raindrops in this method, which is an array of $1 \times N_{var}$. The array is given as follows:

$$Raindrop = [X_1, X_2, X_3, ...X_N] \quad (13)$$

Matrix of raindrop is as follows:

$$Raindrop\ Population = \begin{bmatrix} Raindrop_1 \\ Raindrop_2 \\ Raindrop_3 \\ \vdots \\ Raindrop_{N_{POP}} \end{bmatrix} = \begin{bmatrix} X_1^1 & X_2^1 & X_3^1 & \cdots & X_{N_{\text{var}}}^1 \\ X_1^2 & X_2^2 & X_3^2 & \cdots & X_{N_{\text{var}}}^2 \\ X_1^3 & X_2^3 & X_3^3 & \cdots & X_{N_{\text{var}}}^3 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ X_1^{N_{POP}} & X_2^{N_{POP}} & X_3^{N_{POP}} & \cdots & X_{N_{\text{var}}}^{N_{POP}} \end{bmatrix} \quad (14)$$

The cost of raindrop can be given as

$$C_i = Cost_i = f(X_1^i, X_2^i, X_3^i, ...X_{N_{var}}^i) \quad (15)$$

where N_{pop} is numbers of raindrop and N_{var} number of designed variables.

Raindrop having the minimum value is taken as sea. Nsr is the sum of river and sea which is given as:

$$N_{sr} = Nos\,of\,rivers + 1 \quad (16)$$

$$N_{raindrop} = N_{pop} - N_{sr} \quad (17)$$

$$N_{sn} = round\left\{ \left| \frac{\text{Cos}\,t_n}{\sum_{i=1}^{N_{sr}} \text{Cos}\,t_i} \right| \times N_{raindrop} \right\} \quad (18)$$

where $n = 1, 2, ...N_{sr}$.

N_{sn} is the number of streams which flow to the specific river or sea.

Rain falling to ground creates streams which flow to the river or generate a river. All water from streams and rivers finally goes to the sea. Flow of stream to a river considering a random distance can be given as:

$$X \in (0, C \times d), C > 1 \quad (19)$$

where d is the distance between the river and stream, C is the nos. of flow in different stream. X is a random number between 0 and value of $(C \times d)$. Using the same concept for river water to sea we can write:

$$X_{stream}^{i+1} = X_{stream}^i + \text{rand} \times C \times (X_{river}^i - X_{stream}^i) \quad (20)$$

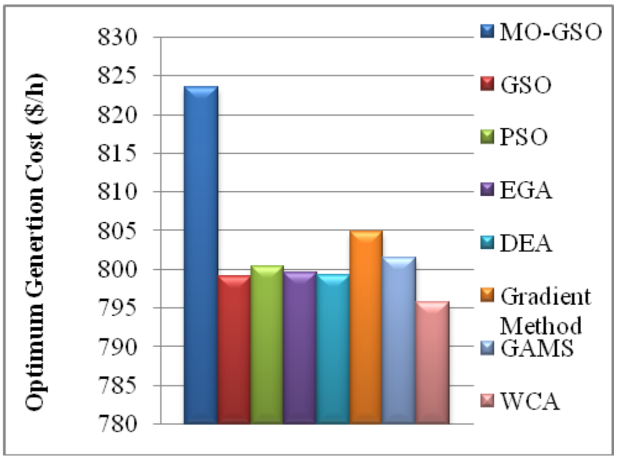

***Fig. 2**: Optimum Generation cost (in $/h) obtained by different algorithm.*

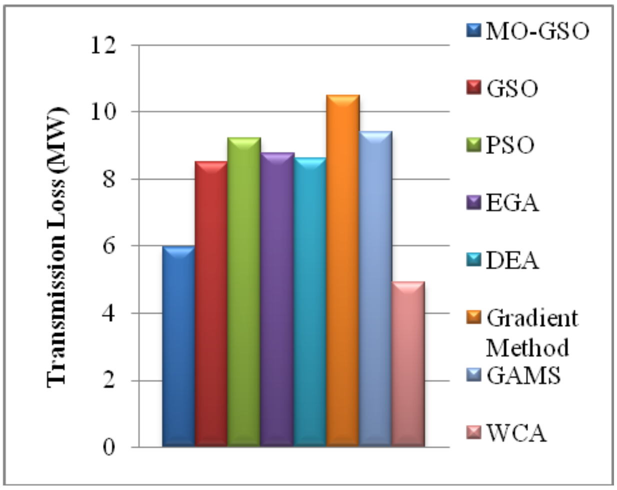

***Fig. 3**: Transmission Loss (in MW) obtained by different algorithm.*

$$X_{river}^{i+1} = X_{river}^{i} + \text{rand} \times C \times (X_{sea}^{i} - X_{river}^{i}) \tag{21}$$

where rand is a random number ranging from 0 to 1.

$$d_{\max}^{i+1} = d_{\max}^{i} - \frac{d_{\max}^{i}}{\max\ iteration} \tag{22}$$

$$X_{stream}^{new} = LB + \text{rand} \times (UB - LB) \tag{23}$$

$$X_{stream}^{new} = X_{sea} + \mu \times \text{rand}(1, N_{\text{var}}) \tag{24}$$

5. RESULT AND DISCUSSION

The potential of the Water Cycle Algorithm have been assessed to resolve two different cases. In the first case the generation scheduling problem with transmission loss when there is no system congestion is considered and in the second case the line congestion management problem is explored in this study. Congestion due to line outage with a sudden spike in load on a specific bus (Case 2, Scenario 1) and corresponding increase in load across all buses (Case 2,Scenario-2) are considered. The WCA's

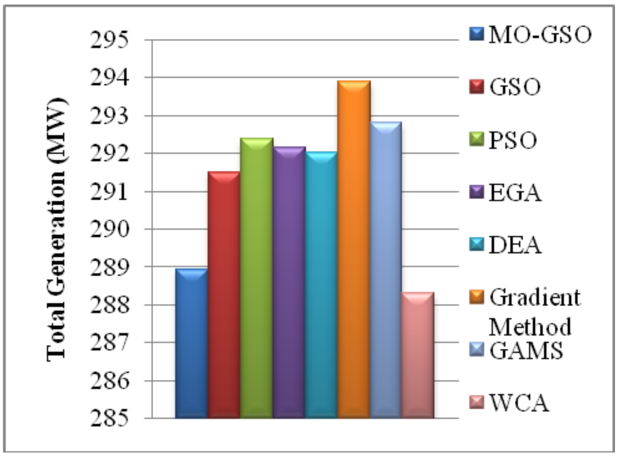

***Fig. 4**: Total Generation (in MWs) obtained by different algorithm.*

relevant parameters are: Total number of variables (nd) is 25, Total number of population (npop) is 10, Total number of rivers and seas (Nsr) is 4, Maximum iteration (max it) is 100, and dmax = 10e-5.

5.1 Case Study I:

In this case, consideration of the bid price is not accounted for congestion management, so the main aim in this case is to reduce the generator fuel cost as well as the minimization of transmission loss without creating congestion in the system, which is considered as the ideal/base case.

5.1.1 Simulation Results on IEEE 30 Bus Test System

On a typical IEEE 30 system, the generation scheduling problem with transmission loss is examined. The IEEE 30 bus system contains of 41 transmission lines of which 4 branches have the transformer tap settings. Buses 10, 12, 15, 17, 20, 21, 23, 24 and 29 are shunt compensation buses. This proposed work is implemented using MATLAB. Table 1 presents the comparison of proposed WCA Technique for single objective optimization problem with different optimization algorithms such as MO-GSO, GSO, PSO, EGA, DEA, the gradient technique and GAMS. The flow chart of the water cycle algorithm is depicted in Figure 1.The optimum generation cost as determined by various algorithms is represented graphically in Figure 2, where different optimization techniques are represented in the x-axis and optimum generation costs are represented in the y-axis. It is shown in Figure 2 that the generation costs obtained by various algorithms MO-GSO, GSO, PSO, EGA, DEA, Gradient Technique, GAMS, and WCA) are 823.54 $/h, 799.06 $/h, 800.41 $/h, 799.56 $/h, 799.29 $/h, 804.85 $/h, 801.52 $/h, and 797.7178 $/h, respectively. Graphically, it can be observed that with the proposed WCA optimization technique, the optimum generation cost is 797.7178 $/h, which is the lowest among the

Table 1: *Comparison of optimum generation cost and transmission loss using different optimization techniques.*

Sl. no	Generator number and objective function values	MO-GSO [10]	GSO [10]	PSO [10]	EGA [20]	DEA [20]	Gradient method [20]	GAMS [20]	Proposed WCA
1.	G1	129.25	174.92	176.96	177.28	176.26	187.22	177.1	167.8381
2.	G2	49.52	44.15	48.98	48.93	48.56	53.78	48.8	37.4942
3.	G3	30.04	21.76	21.30	21.29	21.34	16.95	21.4	20.7624
4.	G4	35.09	25.73	21.19	20.49	22.06	11.29	21.5	18.3606
5.	G5	24.26	11.12	11.97	11.93	11.78	11.29	12	24.8789
6.	G6	21.18	13.81	12.0	12.23	12.02	13.36	12	18.9658
7.	Total Generation (in MWs)	288.93	291.49	292.4	292.15	292.02	293.89	292.8	288.3
8.	Optimum Generation Cost (in $/h)	823.54	799.06	800.41	799.56	799.29	804.85	801.52	797.7178
9.	Transmission losses (in MW)	5.94	8.48	9.22	8.75	8.62	10.48	9.4	4.90

Table 2: *Congestion in line 1-2.*

Congested Line	**Line Limit (MVA)**	**Current Flow (MVA)**	**Violation (MVA)**
1-2	130	164.737	34.737

Table 3: *Congestion in line 1-3, 3-4, 4-6.*

Congested Line	**Line Limit (MVA)**	**Current Flow (MVA)**	**Violation (MVA)**
1-3	130	153.587	23.587
3-4	130	145.657	15.657
4-6	90	96.54	6.54

mentioned algorithms in Figure 2, whereas MO-GSO represents the optimum generation cost of 823.54 $/h. Figure 3 represents the transmission loss in the system, where different optimization techniques are represented on the x-axis and the y-axis represents the transmission loss value obtained by the various algorithms. The different optimization techniques employed are MO-GSO, GSO, PSO, EGA, DEA, Gradient Technique, GAMS, and WCA and their transmission loss values are 5.94 MW, 8.48 MW, 9.22 MW, 8.75 MW, 8.62 MW, 10.48 MW, 9.4 MW, and 4.90 MW, respectively. The transmission loss obtained by the WCA algorithm is shown graphically in Figure 3 to be the lowest among the methods discussed in the article, i.e. 4.90 MW, which is lower than the MO-GSO method's value of 5.94 MW. Figure 4 represent the total generation obtained by various algorithms, where the x-axis represents the different optimization techniques and the y-axis represents the total generation with respect to the six numbers of generators employed in the IEEE 30 bus system. The total generation of power employed with MO-GSO, GSO, PSO, EGA, DEA, Gradient technique, GAMS, and WCA are 288.93 MW, 291.49 MW, 292.4 MW, 292.15 MW, 292.02 MW, 293.89 MW, 292.8 MW, and 288.3 MW, respectively. It is shown in Figure 4 that the highest generation is 293.89 MW and the lowest generation is 288.3 MW. Figure 5and 6 represents the convergence graph of generator fuel cost and transmission loss respectively in IEEE 30 bus system in ideal / base case.

This shows that the WCA techniques have better objective function values compared to other above mentioned optimization techniques.

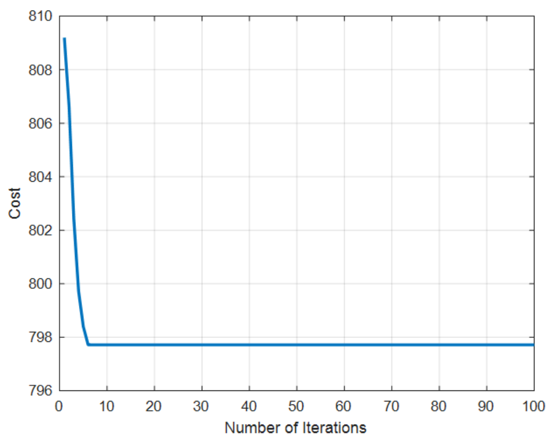

Fig. 5: *Cost convergence graph for ideal case.*

5.1.2 Simulation Results on IEEE 118 Bus Test System

The IEEE 118 bus system considered for this study is shown in the Figure 7. It has 118 buses, 186 transmission lines, 54 generator units and 91 loads and 9 transformers. The system has total real power load of 3996 MW and total reactive power load of 1438 MVAR. In this case minimization of generator fuel cost and minimization of transmission loss is tested in IEEE 118 bus system without creating congestion in the system by utilizing water cycle algorithm where optimal generation cost and transmission loss are 57340.72 $/h and 36.752 MW

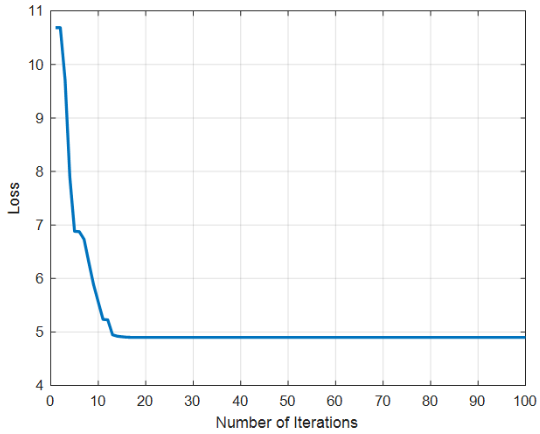

Fig. 6: Loss convergence graph for ideal case.

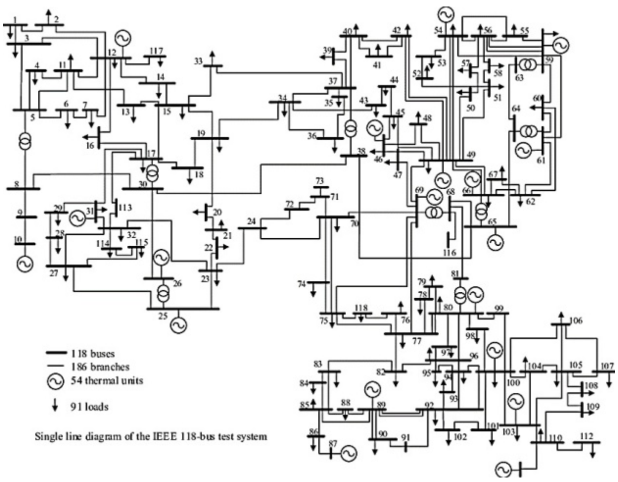

Fig. 7: IEEE 118 bus.

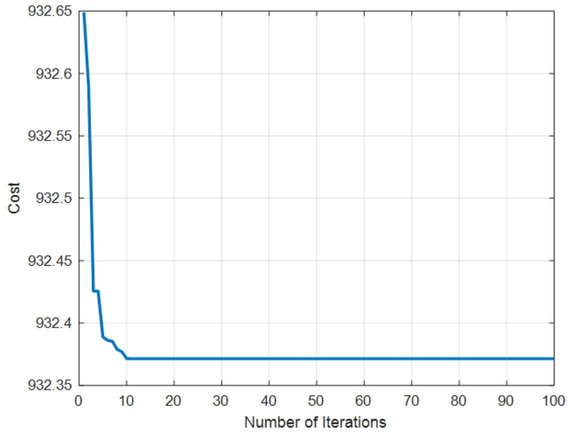

Fig. 8: Cost convergence graph for scenario 1.

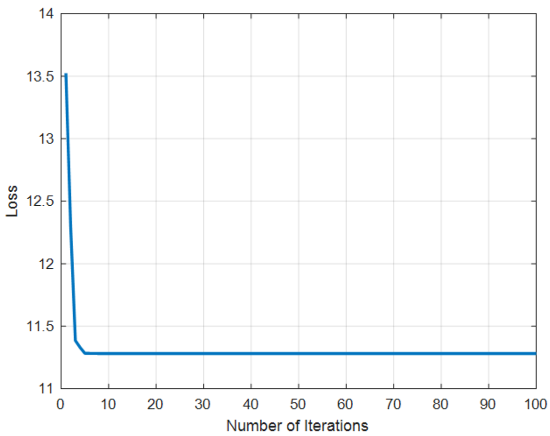

Fig. 9: Loss convergence graph for scenario 1.

respectively. It is observed that the value of optimum generation and transmission loss cost utilizing WCA is reduced with respect to MO-GSO.

5.2 Case Study II

In this case, the main objective is to minimize the total congestion management expense. The proposed methodology is tested in IEEE 30 bus system. Two scenarios occur in this case, namely:

Scenario 1: Outage of the line 3-4 and increased the load at bus 2 by 250 % and the results are represented in Table 2.

Scenario 2: Creation of congestion by outage of the line 1-2 and increased the load by 20% in all buses and the results are represented in Table 3.

5.2.1 Scenario 1: Outage of the line 3-4 and increased the load at bus 2 by 250 percent [21-22].

In this case outage of the line is performed between buses 3-4 and increased the load at bus 2 by 250 %. In this scenario, the load flow has been performed and the line flows are analysed for each branch. It observed that the power flow between buses 1 and 2 is about 164.737 MVA, which is higher than the line flow limit of 130 MVA. This is shown in the Table 2. Since this line is overloaded it means congestion has occurred in the said line [21-22]. Comparison of congestion cost and transmission line loss with WCA and without WCA is presented in Table 4. In Table 4, it is presented that transmission loss is reduced from 15.763 MW to 11.2813 MW by applying WCA with respect to the normal condition, i.e., without WCA. Again, it is presented in Table 4 that the congestion cost is reduced from 941.8606 $/h to 932.3713 $/h with respect to the normal condition, i.e., without WCA, and hence congestion cost and transmission loss are mitigated with the help of WCA. Figure 8 and 9 represents the convergence graph of congestion cost and transmission loss in scenario 1.

5.2.2 Scenario 2: Outage of the line 1-2 and increased the load by 20% in all buses. [21-22]. The result of the load flow in scenario 2 is presented in Table 3. It has been observed that three lines are overloaded. The power flows in line 1-3 and line 3-4 are 153.587 MVA and 145.657 MVA, respectively, and the line flow limit is 130 MVA.

Table 4: *Comparison of Congestion Cost and Transmission Line Loss with WCA and without WCA.*

Generator number and objective function values	With congestion					
	Outage of the line 3-4 and increased the load at bus 2 by 250 %			Outage of the line 1-2 and increased the load by 20% in all buses		
	Without WCA	With WCA	ΔP_g	Without WCA	With WCA	ΔP_g
Pg1	198.591 MW	185.692 MW	8.2809 MW	189.563 MW	197.8544 MW	30.0163 MW
Pg2	60.962 MW	48.077 MW	10.5828 MW	73.776 MW	71.0085 MW	33.5143 MW
Pg5	15.868 MW	20.101 MW	0.6614 MW	34.094 MW	20.0650 MW	0.6974 MW
Pg8	23.765 MW	32.758 MW	14.3974 MW	11.627 MW	19.2783 MW	0.9177 MW
Pg11	12.500 MW	11.456 MW	13.4229 MW	20.340 MW	24.1475 MW	0.7314 MW
Pg13	20.027 MW	29.148 MW	10.1822 MW	39.498 MW	30.6808 MW	11.715 MW
Total generation	331.713 MW	327.232 MW	57.5276 MW	368.899 MW	363.0345 MW	77.5921 MW
Transmission loss	15.763 MW	11.2813 MW		28.820 MW	22.9546 MW	
Congestion Cost	941.8606 $/h	932.3713 $/h		1112.76 $/h	1068.5885 $/h	

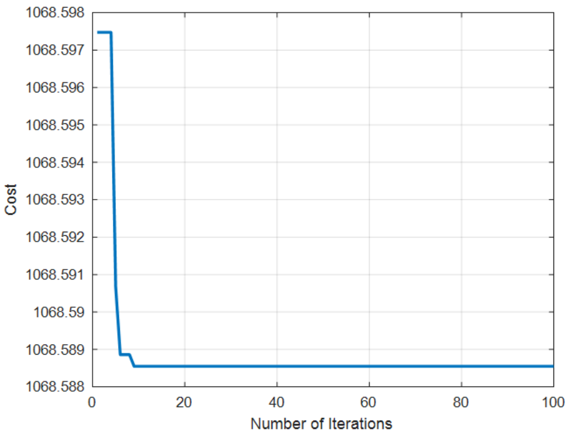

Fig. 10: *Cost convergence graph for scenario 2.*

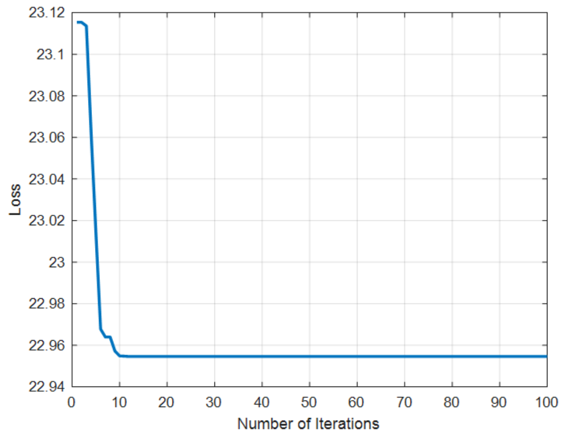

Fig. 11: *Loss convergence graph for scenario 2.*

In line 4-6 power flow is 96.54 MVA, and the limit is 90 MVA. So the power flow violation in each case is 23.587 MVA, 15.657 MVA, and 6.54 MVA, respectively. The total violated amount of power is 45.784 MVA. So it is observed that the congestion occurs in lines 1-3, 3-4 and 4-6. Now it is shown in Table 4 that the transmission loss is reduced from 28.820 MW to 22.9546 MW by employing WCA with respect to the normal condition, i.e., without WCA. Congestion cost in scenario 2 is also reduced to 1068.5885 $/h from 1112.76 $/h by utilizing WCA with respect to the normal condition, i.e., without WCA. Figures 10 and 11 represent the congestion cost and transmission loss in scenario 2.

6. CONCLUSION

The proposed article is divided into two case studies, namely Case Study I and Case Study II. In Case Study I, a water cycle algorithm technique-based generation rescheduling is proposed to alleviate the congestion in the IEEE 30 bus and IEEE 118 bus systems. The Water Cycle Algorithm technique's efficacy for the best result compared with other algorithms such as MO-GSO, GSO, PSO, EGA, DEA, Gradient Method, and GAMS in terms of optimized generation cost and transmission loss has been confirmed. Applying the proposed methodology, transmission loss and optimum generation cost have been reduced by 4.90 MW and 797.7178 $/h respectively for the IEEE 30 bus test system and 36.752 MW and 57340.72 $/h respectively for the IEEE 118 bus test system, considering the base case, i.e., without creating congestion. As a result, compared to the above-mentioned methodologies, the suggested methodology has produced the best overall results. Case Study II is subdivided into two scenarios, namely, scenario 1 and scenario 2. Congestion was caused by the outage of lines 3-4 in scenario 1, which increased the load at bus 2 by 250 percent; it was discovered that the line violation occurred in lines 1-2, i.e., 164,737 MVA. By employing WCA with respect to normal conditions, the transmission loss is reduced from 15.763 MW to 11.2813 MW and the congestion cost is reduced from 941.8606 $/h to 932.3713 $/h. In case of scenario 2, congestion is created by the outage of line 1-2, which increased the load by 20% in all buses and found that violations of the line limit occur in lines 1-3, 3-4, and 4-6, i.e., 153.587 MVA, 145.657 MVA, and 96.54 MVA respectively. By using WCA, the transmission loss and congestion cost are reduced to 22.9546 MW and 1068.5885 $/h respectively, when compared to the normal condition. In the future, the power system operator can use the current solution to manage real-time congestion on the transmission network.

REFERENCES

[1] D. K. Narne, T. A. Ramesh Kumar, and R. Alla, "Effect of partial shading on the performance of various 4×4 PV array configurations," *ECTI Transactions on Electrical Engineering, Electronics, and Communications*, vol. 20, no. 3, pp. 427–437, Oct. 2022.

[2] S. Thorat and V. Kalkhambkar, "Management of a Solar-PV System with Energy Storage," *ECTI Transactions on Electrical Engineering, Electronics, and Communications*, vol. 19, no. 3, pp. 233–245, Oct. 2021.

[3] M. Panto, "Market-based congestion management in electric power systems with exploitation of aggregators," *International Journal of Electrical Power & Energy Systems*, vol. 121, p. 106101, Oct. 2020.

[4] M. El-Azab, W. A. Omran, S. F. Mekhamer, and H. Talaat, "Congestion management of power systems by optimizing grid topology and using dynamic thermal rating," *Electric Power Systems Research*, vol. 199, p. 107433, Oct. 2021.

[5] S. Namilakonda and G. Yesuratnam, "Chaotic darwinian particle swarm optimization for real-time hierarchical congestion management of power system integrated with renewable energy sources," *International Journal of Electrical Power & Energy Systems*, vol. 128, p. 106632, Jun. 2021.

[6] J. R. Chintam and M. J. Daniel, "Real-Power rescheduling of generators for congestion management using a novel Satin Bowerbird optimization algorithm," *Energies*, vol. 11, no. 1, p. 183, Jan. 2018.

[7] Prashant, M. Sarwar, A. S. Siddiqui, S. S. M. Ghoneim, K. Mahmoud, and M. M. F. Darwish, "Effective transmission congestion management via optimal DG capacity using hybrid swarm optimization for contemporary power system operations," *IEEE Access*, vol. 10, pp. 71091–71106, Jan. 2022.

[8] S. C. Raja, S. Prakash, and J. J. D. Nesamalar, "Effective power congestion management technique using Hybrid Nelder–Mead – Grey Wolf Optimizer (HNMGWO) in deregulated power system," *IETE Journal of Research*, vol. 69, no. 8, pp. 5307–5318, Aug. 2021.

[9] D. Asija and P. Choudekar, "Congestion management using multi-objective hybrid DE-PSO optimization with solar-ess based distributed generation in deregulated power Market," *Renewable Energy Focus*, vol. 36, pp. 32–42, Mar. 2021.

[10] S. R. Salkuti and S.-C. Kim, "Congestion management using Multi-Objective Glowworm Swarm Optimization Algorithm," *Journal of Electrical Engineering & Technology*, vol. 14, no. 4, pp. 1565–1575, May 2019.

[11] S. R. Salkuti, "Congestion management using optimal transmission switching," *IEEE Systems Journal*, vol. 12, no. 4, pp. 3555–3564, Dec. 2018.

[12] Sharma and S. Jain, "Gravitational search assisted algorithm for TCSC placement for congestion control in deregulated power system," *Electric Power Systems Research*, vol. 174, p. 105874, Sep. 2019.

[13] D. F. Farzana and K. Mahadevan, "Performance comparison using firefly and PSO algorithms on congestion management of deregulated power market involving renewable energy sources," *Soft Computing*, vol. 24, no. 2, pp. 1473–1482, Apr. 2019.

[14] Batra and S. Ghosh, "A novel approach of congestion management in deregulated power system using an advanced and intelligently trained twin extremity chaotic MAP Adaptive particle swarm Optimization algorithm," *Arabian Journal for Science and Engineering*, vol. 44, no. 8, pp. 6861–6886, Dec. 2018.

[15] M. Moazzami, H. Shahinzadeh, G. B. Gharehpetian, and A. Shafiei, "Optimal TCSC placement for congestion management in deregulated power systems using antlion optimization algorithm," *International Journal of Robotics and Automation (IJRA)*, vol. 8, no. 2, p. 77, Jun. 2019.

[16] P. Tiwari, M. K. Mishra, and S. Dawn, "A two step approach for improvement of economic profit and emission with congestion management in hybrid competitive power market," *International Journal of Electrical Power & Energy Systems*, vol. 110, pp. 548–564, Sep. 2019.

[17] N. K. Patel, B. Suthar, and J. Thakkar, "Transmission congestion management considering voltage stability margin," *SN Applied Sciences*, vol. 3, no. 2, Feb. 2021.

[18] E. Semshchikov and M. Negnevitsky, Congestion management optimization in electric transmission system. in 2018 *Australasian Universities Power Engineering Conference (AUPEC)*, pp. 1-5, IEEE, 2018.

[19] H. Eskandar, A. Sadollah, A. Bahreininejad, and M. Hamdi, "Water cycle algorithm – A novel metaheuristic optimization method for solving constrained engineering optimization problems," *Computers & Structures*, vol. 110–111, pp. 151–166, Nov. 2012.

[20] S. S. Reddy, P. R. Bijwe, and A. R. Abhyankar, "Faster evolutionary algorithm based optimal power flow using incremental variables," *International Journal of Electrical Power & Energy Systems*, vol. 54, pp. 198–210, Jan. 2014.

[21] M. Houndjega and C. Muriithi, "Active power rescheduling for congestion management based on generator sensitivity factor using Ant Lion optimization algorithm," *International Journal of*

Engineering Research and Technology, vol. 11, no. 10, pp. 1565–1582, Jan. 2018.

[22] A. Vengadesan, R. A. Bakkiyaraj, S.Sakthivel "Transmission Congestion Management through Optimal Placement and Sizing of TCSC Devices in a Deregulated Power Network," *Turkish Journal of Computer and Mathematics Education (TURCOMAT)*, vol. 12, no. 6, pp. 5390–5403, Apr. 2021.

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