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Review

Methods and Methodologies for Congestion Alleviation in the DPS: A Comprehensive Review

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Abstract: The modern power system has reached its present state after wading a long path facing several changes in strategies and the implementation of several reforms. Economic and geographical constraints led to reforms and deregulations in the power system to utilize resources optimally within the existing framework. The major hindrance in the efficient operation of the deregulated power system (DPS) is congestion, which is the result of the participation of private players under deregulation policies. This paper reviews different setbacks introduced by congestion and the methods applied/proposed to mitigate it. Technical and non-technical methods are reviewed and detailed. Major optimization techniques proposed to achieve congestion alleviation are presented comprehensively. This paper combines major publications in the field of congestion management and presents their contribution towards the alleviation of congestion.

Keywords: deregulated power system; congestion; power flow; renewable energy; technical methods; optimization techniques; demand response

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1. Introduction

With technological and industrial developments, power demand has escalated exponentially. It was economically unfeasible to lay down new transmission lines. Local energy resources were not exploited efficiently due to economical and geographical reasons. Therefore, the focus was on the implementation of policies that can allow the increase in generation and fulfill the recursively enhanced demands. Initially, the power system was vertically integrated, where the rights for generation, transmission, and distribution were exclusive to the government. There was a monopoly in the power system and, thus, a dire need to restructure the power system. The power system was then restructured to obtain the DPS, as shown in Figure 1. The entire power system is segregated into three main parts: the generation companies (GENCOS), the transmission companies (TRANSCOS), and the distribution companies (DISCOS). GENCOS are the generation companies which are the owners of generator plants. Their main role is to operate and maintain the generation units. These have unbiased access to the transmission network. The GENCOS may either be a government or a private unit. TRANSCOS are the transmission owner companies which own the transmission network. These companies provide open access to the generators without any bias to a particular generating unit. Generally, this utility is in the public sector as this is the costliest part of the power system. DISCOS are the distribution companies. These companies may either be in private or public sectors. In the deregulated environment, DISCOS are generally restricted to the distribution of energy and offer services for electricity distribution. Apart from these three entities, there is an independent system operator (ISO), which is the ultimate authority in controlling transmission. There are three basic functions of an ISO: to maintain the security of the network, to ensure reliable service quality, and to maintain power system efficiency. There are retailers in the DPS which are segregated from the DISCOS in the deregulated power system as they have the role of offering electricity sales to the end users. Power exchangers (PX) offer a medium to tie electricity supply and demand for existing and forthcoming power markets.

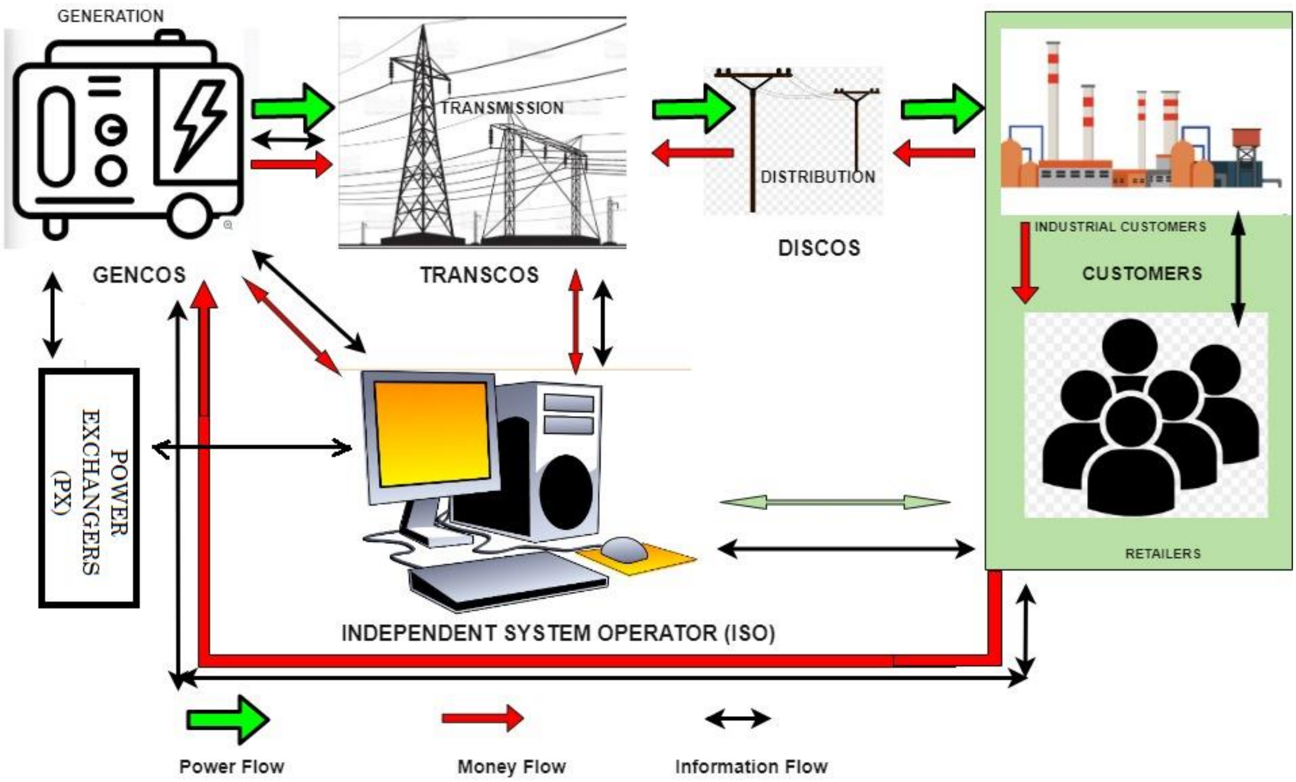

Figure 1. Deregulated power system.

However, there are many hindrances to implementing the deregulation policies. All energy policies include strategies to invite private market players, auction regulations, alleviation of market powers of accomplices, control on energy prices, the autonomy of transmission, and stable and efficient working of the electricity market [1]. With the increased participation of private market players, a new challenge, congestion, is faced by the system operators. In the deregulated power system, numerous private generators supply power to the consumers through power agreements. These generators use common transmission lines without any bias. Sometimes due to faults, extreme weather conditions, undeclared bilateral transactions, etc., one or more transmission lines becomes overloaded and is not able to transfer the contracted power to the loads. This condition is called congestion. Congestion not only affects the system physically, but it also adversely affects the system's economy. The main reason for this menace is the overloading of existing transmission lines, mismatched generation and transmission, unforeseen increases in demand, outage of one or more generators, and failure of system equipment [2].

As network expansion is a costly option to meet escalated demand, congestion management is an economic option. Congestion mitigation or alleviation means the reduction or redistribution of excess power flowing through the overloaded transmission lines. By managing congestion, the available power can be transmitted efficiently without breaching the system constraints. Thus, this paper provides a comprehensive review of the work published in the literature in the field of congestion management (CM). Different techniques are proposed in the literature to alleviate congestion. Techniques for CM are broadly categorized as cost-free and non-cost-free methods. These methods are based on the operational cost of a system. In a cost-free methods system, operational cost is considered constant while non-cost-free methods affect system economics [3]. Cost-free methods are applied on the transmission lines and are, hence, managed by the transmission system operator (TSO) only. The cost-free methods include modification of the system topology, installing transformer taps, and implementing phase shifting transformers and flexible AC transmission system (FACTS) devices. On the other hand, non-cost-free methods involve generator rescheduling and load curtailment. Thus, these methods are under the disposal of generator companies (GENCOS) and distribution companies (DISCOS) only [4].

This review paper is divided into four sections. Section 1 gives a brief introduction about CM in the DPS. Methods to alleviate congestion are explained in Section 2. Section 3 details different optimization techniques/algorithms with their pseudocodes for CM. The paper is concluded in Section 4.

2. Methods to Alleviate Congestion

Congestion also occurred before the power system was deregulated. The main reason behind the congestion was the weakening or deterioration of the transmission lines due to the scheduled outages in the system. Then, the congestion mitigation was achieved by the rescheduling of power, changes in transformer taps, and phase angle regulation. Congestion is the undesired condition in the deregulated power system when the lines are incapable of transmitting the scheduled power to the loads. This condition arises because of the escalation in the number of power transactions due to the enhanced number of market participants. Private players in the generation, transmission, or distribution affect congestion differently. The effect differs in accordance with the availability of power in the neighborhood and as per the severity of demand in the system. The location of private generators is also one of the major factors affecting congestion. The power transfer in long transmission lines is limited by the magnitude of the voltages at the two ends, voltage angles, the reactance between the two ends, and the corresponding reactance angle. Apart from these features, the climatic condition, geographical features, the age of the transmission lines, and the increase in load demand are some of the physical features restricting the amount of power flow in the transmission lines. To decide the appropriate method of CM, it is essential to know the major impacts of electrical congestion The effects are listed as follows:

(a) System disturbances causing added outages in an interrelated system;
(b) Reduced market efficiency;
(c) Hike in energy prices;
(d) With an increase in electricity charges, the loads are enforced to decrease the power consumption;
(e) Adverse security concerns;
(f) Operation of the system with stability margins;
(g) Frequent initiation of cascade tripping.

The hike in energy prices results in an uneconomical and inefficient operation of the power system. Here, the independent system operator (ISO) plays the role of setting and implementing certain regulations to ensure that the market participants are controlled for acquiring a certain safe level of reliability in the system [5]. The ISO plays a very significant role in sustaining system reliability and safety, keeping the constraints of the electrical power system (EPS) within defined limits [6]. The methods implemented by an ISO to mitigate congestion may be based on operational costs. Assuming a variable operational cost, these methods may be segregated into market-based and non-market-based methods. These methods are also called non-cost-free methods or non-technical methods. Another set of methods to alleviate congestion are constant operational cost methods or cost-free/technical methods. A detailed classification of methods to alleviate congestion is shown in Figure 2.

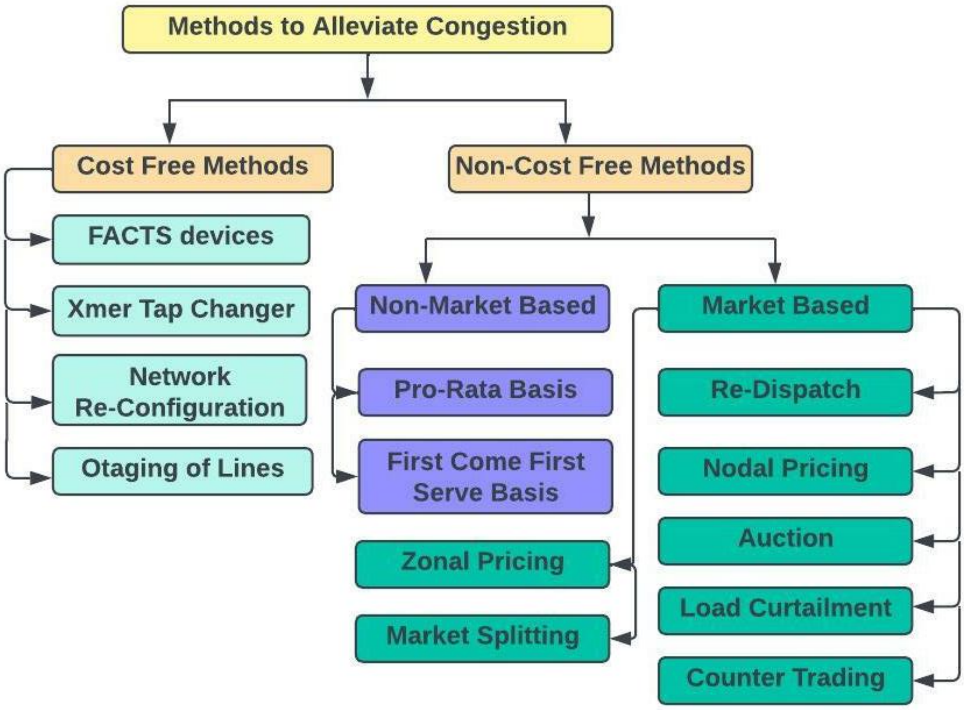

Figure 2. Orthodox methods to mitigate congestion [7].

2.1. Cost-Free Methods

These methods consider the operational costs constant. These are also called technical methods. Here, the economy of the system is not affected by the application of these methods to alleviate congestion. Technical methods are further classified into the following.

2.1.1. Application of a Flexible AC Transmission System (FACTS)

The implementation of a FACTS device is the most effective way to mitigate congestion in the DPS due to their effectiveness in manipulating EPS parameters rapidly. FACTS devices are very efficient in maintaining the voltage profile at the buses. These devices are very useful in reducing power loss in the transmission lines, thus reducing the overloading of the lines. Available transfer capability (ATC) is increased efficiently by the implementation of these devices. FACTS can be employed in series, shunt, and a combination of the two. A number of methods to implement FACTS devices are investigated and proposed in the literature. Different types of FACTS devices depending on their location in the DPS are presented in Table 1, in which P represents active power and Q represents the reactive power of the system.

In the current deregulated power system, due to the advancement of power electronic technology, the employment of FACTS devices has escalated manifold. The use of a gate turn-off (GTO) thyristor for the practical implementation of efficient power transactions is reported in [9]. To reap the maximum outcome of the FACTS device, the optimal location of the FACTS is proposed in the transmission network [10–12]. The effectiveness of FACTS implementation for congestion management (CM) depends on the efficiency of the FACTS to reduce CM cost and is reported in [13]. Locational marginal prices (LMPs) are used as a base to locate the most congested lines in the system for employing series FACTS devices. The effect of the device on pool market pricing is established in [14]. The sensitivity factor approach to locating the UPFC for relieving overburdened transmission lines is reported. The efficiency of the UPFC to mitigate congestion is enhanced by suitably locating the device using sensitivity factors [15]. Multiple FACTS devices are reported in the literature to alleviate congestion more effectively. Series FACTS devices, such as TCPAR, IPFC, and TCSC, are located in the transmission network and effectively implement the devices by using sensitivity factors such as the power flow performance index (PI), the line utilization factor (LUF), and the disparity line utilization factor (DLUF), which are used in [16,17]. SSSC, UPFC, and STATCOM are very efficient devices used in the power system to mitigate congestion. Power sensitivity factors are reported in [18] together with the penetration of windfarm to determine the effect of FACTS devices on mitigating congestion. The manipulated voltage profile, enhanced power loss, reduced security margin, and reduction in the ATC of the system are the most severe effects of congestion. Shunt FACTS devices, such as SVC, and the series FACTS device TCSC are implemented in [19] to enhance the total transfer capacity (TTC) and the security margin of the congested power system. IPFC is implemented in [20,21] to optimize the multiobjective function to reduce system power losses and to enhance the static security margin for alleviating congestion in the overburdened lines. The papers employed artificial intelligent controllers (AIC) and gravitational search algorithms (GSA). The example to illustrate CM by the implementation of FACTS devices is taken from [21] and shown in Figure 3.

Table 1. Various types of FACTS devices are connected in the DPS to mitigate congestion [8].

FACTS Devices	Nomenclature	Position in the EPS	Controlled Parameter
SVC	Static VAR compensator	Shunt	Q
TCR	Thyristor controlled reactor		Q
TSC	Thyristor switched capacitor		Q
TSR	Thyristor switched reactance		Q
STATCOM	Static synchronous compensator		Q
TCSC	Thyristor controlled series capacitor	Series	P
IPC	Interphase power controller		P
TSSC	Thyristor switched series capacitor		P
TCSR	Thyristor controlled series reactor		P
TSSR	Thyristor switched series reactor		P
TCVR	Thyristor controlled voltage regulator		P
SSSC	Static synchronous series compensator		P
IPFC	Interline power flow controller	Series–Series	P and Q
UPFC	Unified power flow controller	Series–Shunt	P and Q

Here, the from the figure it can be observed that after overloading the load buses of the IEEE 30 bus system, the power loss of the system is enhanced, creating congestion. With the help of IPFC, the real and reactive power losses are significantly reduced, alleviating congestion.

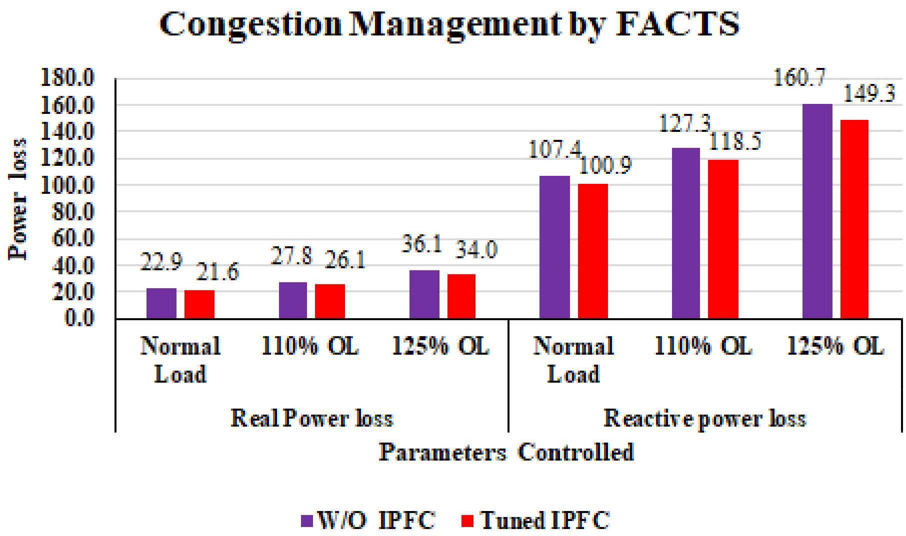

Figure 3. Illustration of CM by FACTS.

2.1.2. Phase Shifting Transformers

The phase shifting transformer (PST) for CM in the DPS is discussed in the literature. The PST reallocates the active power flows in the transmission lines to relieve the overloaded lines to mitigate congestion. The benefit of implementing the PST is that it sidesteps the excess power generation and re-dispatch, which involves the economics of the system. A 24 h day ahead schedule is proposed for the PST in [22,23] to reduce the number of interventions of the operator. The real power is diverted from congested to the underloaded lines to reduce congestion in the system using PST and employing the PSO for ideal PST phase settings [24]. To apprehend this change, load tap changers are deployed to induce a flexible phase shift to manipulate the subsequent phase angle.

Figure 4 illustrates the result of the application of the PST in reducing the unscheduled power flow (UF) causing congestion in the system. In Area 1, the UF is reduced from 110 MW to 51.1 MW; in Area 2, the UF falls from 12.9 MW to 8.1 MW, with a 36.8% reduction; and in Area 3, the UF is again reduced from 12.9 MW to 8.1MW.

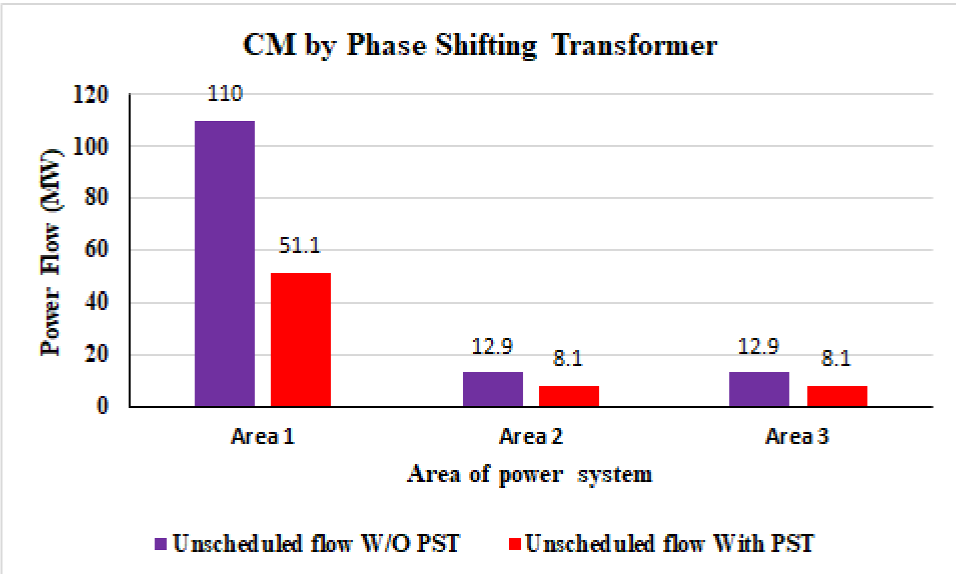

Figure 4. CM by phase shifting transformers.

2.1.3. Network Reconfiguration

Network reconfiguration means altering the line topology by opening and closing the sectionalized and tie switches between the interconnected lines in distribution systems. Before reconfiguration, it is essential to locate the most congested area to which reconfiguration is to be applied. In [25,26], a genetic algorithm (GA)-based reconfiguration algorithm is proposed to find the most congested area to reduce the system losses and alleviate the over-voltages for mitigating congestion. A method to optimally establish the system configuration for mitigating congestion following system security limits under the contingency condition is proposed in [27]. Dynamic tariff (DT) and re-profiling products are integrated here to mitigate congestion in a system with several distributed generation resources. Figure 5 presents the CM by network reconfiguration [26].

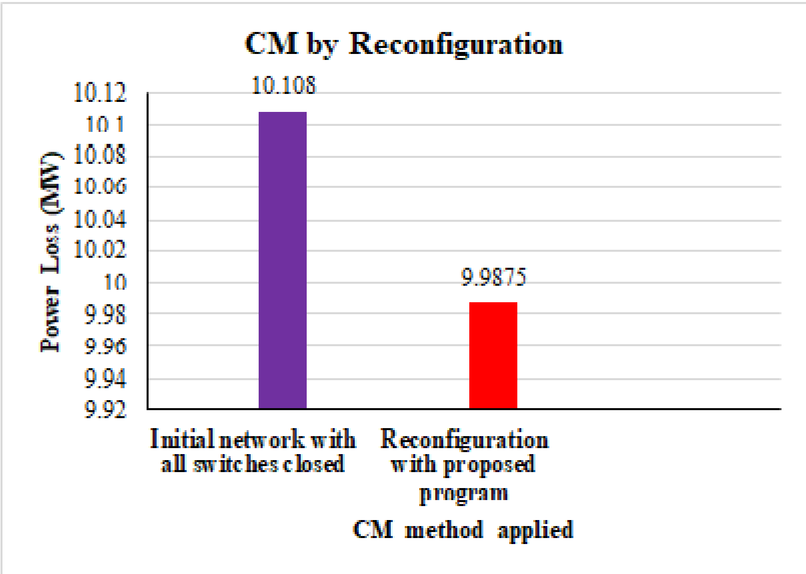

Figure 5. Illustration of CM by network reconfiguration.

From Figure 5, it can be observed that for the reconfigured network with some switches open, power loss in the system is reduced from 10.108 MW to 9.9875 MW, hence reducing congestion in the system.

2.1.4. Available Transfer Capacity (ATC) Enhancement-Based CM

ATC is the capacity of transmission lines to supply power over and above the scheduled and agreed power demand to be utilized for commercial purposes. ATC can be mathematically represented as

$$ATC = TTC - TRM - ETC - CBM.$$

TTC is defined as the total transfer capacity, TRM is defined as the transmission reliability margin, ETC is defined as the existing transmission commitment, and CBM is the capacity benefit margin. The value of TRM is taken as 10% of the TTC while CBM is related to the generators' profit and is usually taken as zero. ETC is different for different systems and is taken accordingly. CM can be effectively achieved by enhancing the ATC of the system. The transmission congestion distribution factor (TCDF) is employed to locate the wind generators (WGs) for enhancing the ATC of the system [28]. Various FACTS devices, such as UPFC, STATCOM, and SSSC, are optimized in [29] for their parameters to enhance the ATC by employing PSO. TCSC is employed in a congested system with ACPTDF as a location sensitivity factor, a parameter being optimized by metaheuristic evolutionary particle swarm optimization (MEEPSO) for ATC enhancement to mitigate congestion [30]. The CM by ATC enhancement for [29] is illustrated in Figure 6.

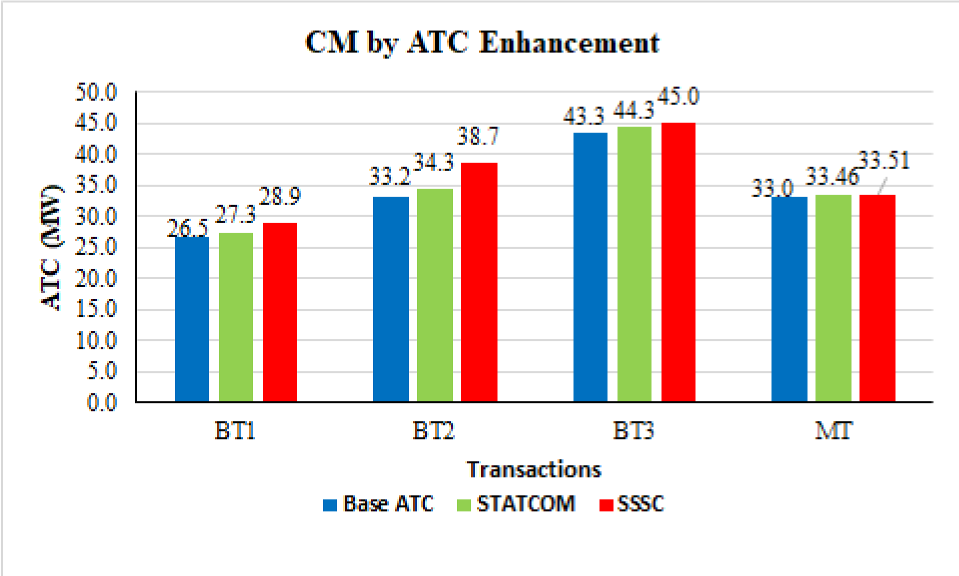

Figure 6. Illustration of CM by ATC enhancement.

Figure 6 shows the increment in the ATC of the system under the contingency condition by applying STATCOM and SSSC as the FACTS devices. With the enhancement of the ATC, more power can be transmitted without reaching the thermal and voltage limits of the line.

2.2. Non-Cost-Free Methods

Non-cost-free methods are those that affect the economy of the DPS. In these methods, the economic aspects of the system are considered, leaving behind the technical aspects to mitigate congestion. The operational cost of the DPS is kept at the highest priority while applying these methods.

2.2.1. Congestion Alleviation by Generator Rescheduling and Load Curtailment

Generator rescheduling (GR) with or without load curtailment (LC) is an extensively used method to relieve congested lines. In this method, the generator's active power output is rescheduled by the bid submitted by the respective generators. In the deregulated market, congestion occurs due to contractual settlements between the sender and buyers. These settlements may be declared or undeclared. When the generators are rescheduled, there is an enhancement in the cost of generation. Thus, the cost of rescheduling is kept as low as possible by the monetary agreements in the pool electricity market. When the congestion remains even after the rescheduling process is complete, load curtailment is performed where the demand of the system is reduced to mitigate congestion. For determining the participating generators in the rescheduling process, sensitivity factors such as transmission congestion distribution factors (TCDFs) are proposed in [31] and the cost of rescheduling is reduced by applying PSO. A generator sensitivity factor (GSF) is applied to decide the participating generator. The ant lion optimization algorithm (ALO) and the flower pollination algorithm (FPA) are proposed to reduce congestion cost [32,33]. In the day-to-day electricity market, CM is achieved by GR which, in turn, is based on the proposed relative electrical distance (RED) method in [34]. The cuckoo search algorithm (CSA) is applied to reduce the congestion cost in a system with renewable energy resources [35]. GR is performed by applying voltage-dependent load modeling and an integrated pumped storage hydro unit (PSHU) is proposed in [36,37]. The site for the PSHU is decided by the bus sensitivity factor, while the generator participating in rescheduling is decided by the GSF. A moth–flame optimization (MFO) is proposed to lessen the cost of congestion while reducing the amount of active power rescheduled [38]. To decide the range of real and reactive power rescheduled for minimum congestion cost, power sensitivity factors are proposed. Further, the black hole algorithm (BHA) is suggested to re-dispatch the generators in [39]. CM from [32] is demonstrated in Figure 7.

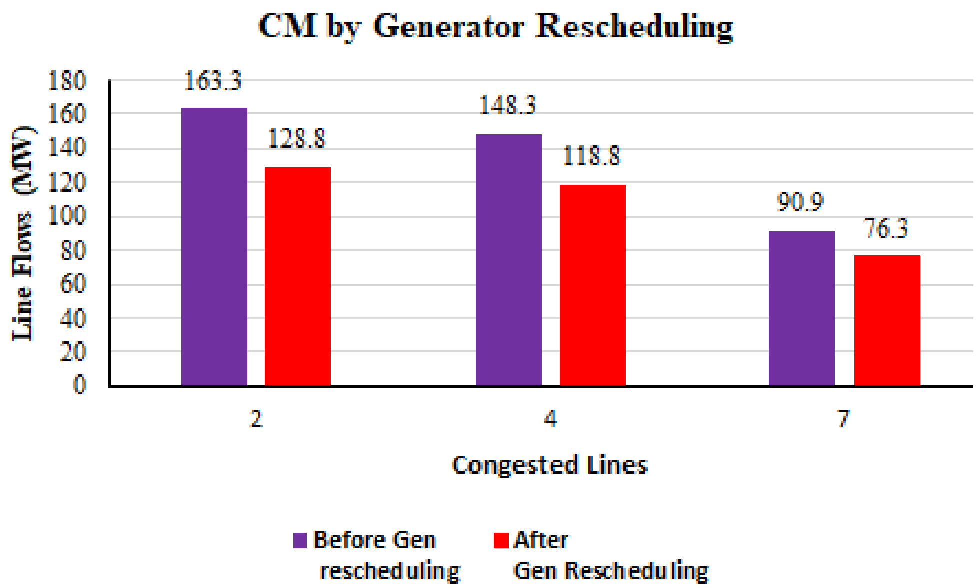

Figure 7. CM by generator rescheduling.

Figure 7 illustrates the redistribution of line flows in the previously congested lines 2, 4, and 7. Initially, the power flow violates the limits creating congestion. With generator rescheduling, the overloaded lines 2, 4, and 7 are relieved to carry 128.8 MW, 118.8 MW, and 76.3 MW only.

2.2.2. First-Come, First-Served (FCFS) and Pro-Rata Method

The capability of the network is assigned by the order in which the ISO receives demands from the buyers for contractual transmission services. The first request received is assigned as the first network capacity. Then, until the network capacity is exhausted, the other requests in the sequence are allowed to receive. The advantage of this first-come, first-served strategy is that it helps private market players generate long-term forecasts. This makes the system more secure as the system operator knows the transmission requirements well in advance. This process seems to be very efficient for bilateral trading but is not very suitable for deciding the priority in the pool-based energy market or day-ahead electricity market as mentioned in [40]. To manage the disadvantage of the first-come, first-served method, another method is the pro-rata basis of network allocation. In this method, the network allocation is not based on the sequence of requests made, but rather on the proportion of their proportional requirement [41].

2.2.3. Auction-Based Methods

In the DPS, unbiased transmission access is ensured by the transmission system operator (TSO). The transmission capacity allocation is performed with the constraints. The auction of transmission capacity is undertaken by the TSO based on the bids submitted by respective market players in the pool-based electricity market. The basis of the allocation of transmission rights carried out by the TSO is to provide a congestion-free environment in the power system, as proposed in [42,43]. Splitting of the congested market is proposed with real-time market clearing hardware which accepts the auction data and implements them to clear the congested market in the power system [44]. A detailed review of congestion management employing generator rescheduling, FACTS implementation, and auction-based CM is presented in [45]. Interruptible load-based and LMP-based auction methods to mitigate congestion are proposed in [46,47]. This method can be illustrated from [46] below.

In Figure 8, the effect of auction-based CM on usual business hours is shown. NILS means the number of load buses with load interruption and PILS is the power interruption invoked. Here, the ISO prefers to reduce the net load interruption constraint; it must reduce the maximum number of interruptible buses when the current market price is lower than before. This way, auction-based CM alleviates the congestion in terms of market price.

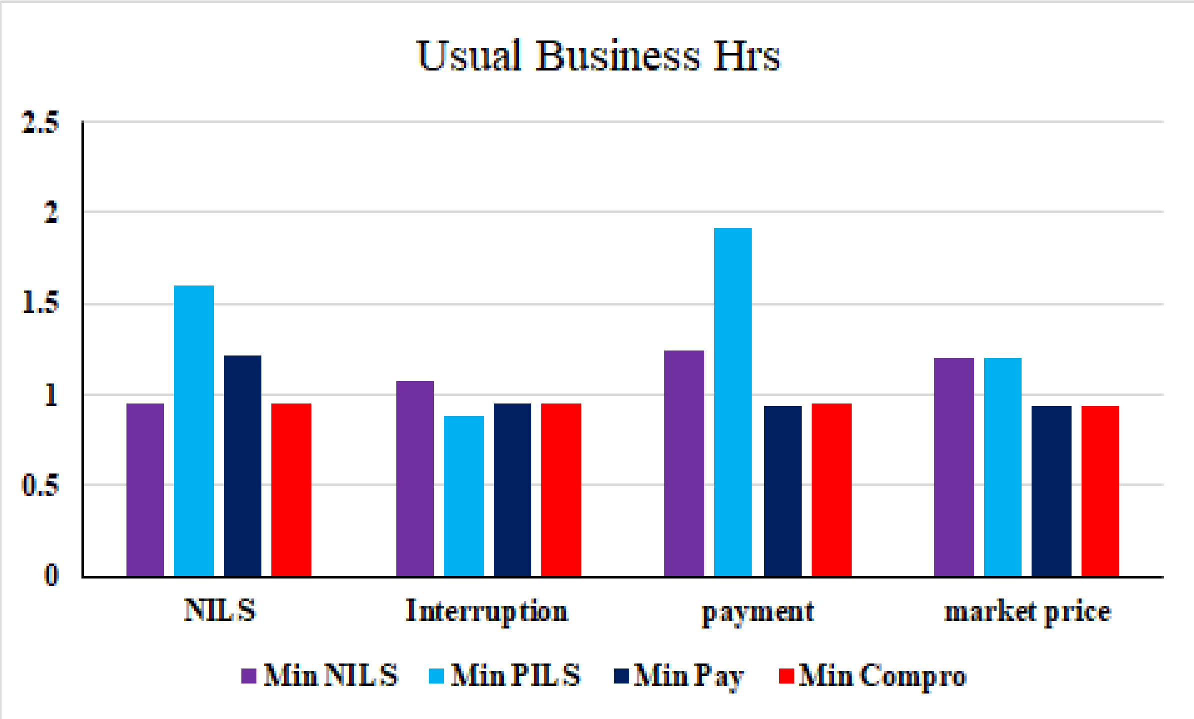

Figure 8. Illustration of CM by the auction-based method.

2.2.4. Load Curtailment-Based Methods

The load curtailment method is a way to mitigate congestion by shutting down some of the loads in the congested transmission system. This strategy of CM includes market splitting where, at first, the dispatch is scheduled without considering constraints. If the congestion persists, then the market is split and cleared individually. Here, the ISO acquires power from a region with a low price and then supplies it to the region with a higher price. This CM method is applied in the Norwegian market. The load curtailment method copes with the existing loads in a way that efficiently mitigates congestion in the network [48]. The load curtailment is kept as small as possible so that the price drop in the congested regions is as low as possible. Willingness to pay for avoiding curtailment is used as a factor to decide the amount of load curtailment, as presented in [49–51]. To illustrate the CM by load curtailment, an example from [52] is shown in Figure 9. Due to unscheduled bilateral and multilateral transactions in the pool-based electricity market, congestion is created. The active power limits for bilateral and multilateral markets are 150 MW and 90 MW, respectively. After congestion, the line flows in congested lines are 151.285 MW and 93.096 MW for bilateral and multilateral transactions, respectively. The loads to be curtailed are selected by optimization techniques. After load curtailment, the congested power for bilateral transactions is reduced to 0.997 MW, while that for multilateral transactions reduces to 2.168 MW only.

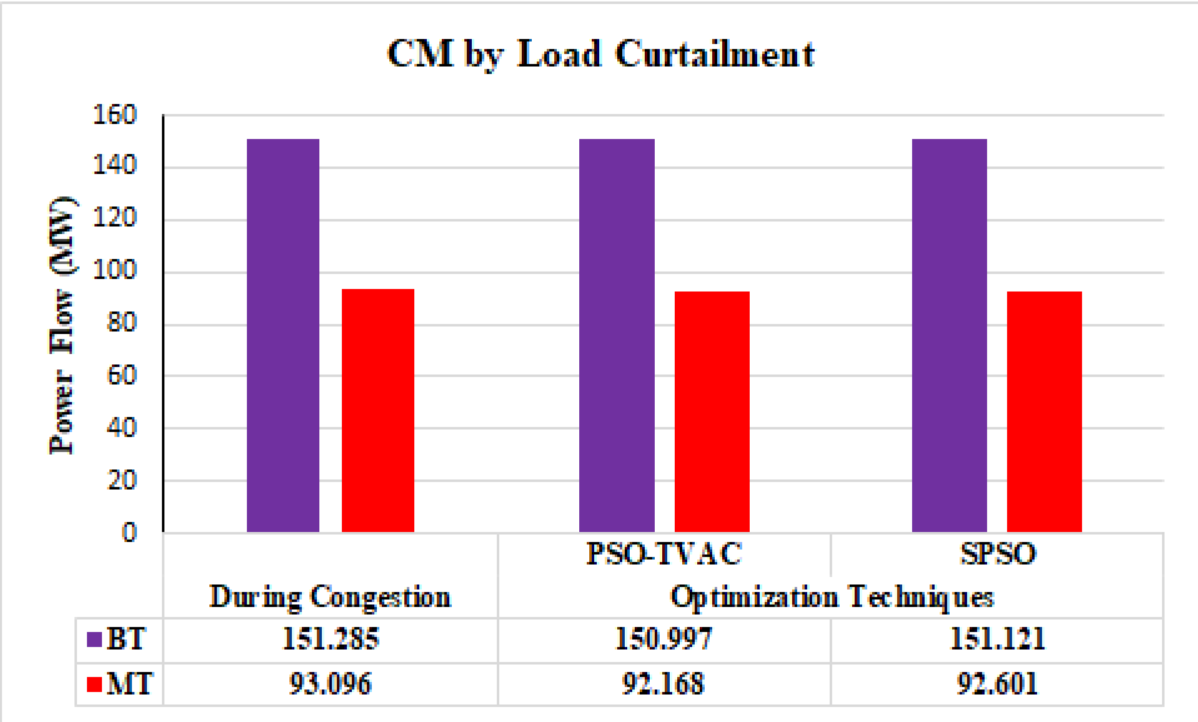

Figure 9. Illustration of CM by load curtailment.

2.2.5. Nodal Pricing (NP) Methods

NP method is a customary method for alleviating congestion in the overloaded power system due to its unique property of efficiently allocating transmission capacity without congesting the network. The nodal price in the optimization problem varies by the location of the node in the congested system. The cost of supplying the successive increment of load, including cost caused by loss due to the increment of load and transmission congestion cost at a bus, is called the locational marginal price (LMP) [53]. The non-linear power system equations are solved by employing GA together with the generator scaling factor to find the LMP for mitigating congestion [54]. Capacity procurement to balance the power market and to locate control reserves is proposed by using the LMP [55]. The semidefinite programming (SDP) relaxation method is proposed to derive LMPs. The signal for the future market is analyzed to reduce losses and alleviate congestion using the LMP [56]. A transactive energy (TE) framework using the distribution locational marginal price (DLMP) for distribution systems is proposed for smart market players playing consumers and suppliers [57]. A breakdown of NP for generation, transmission, and voltage constraints in the New England power system for CM is proposed in [58].

Utilization of congestion cost and optimal node price for CM in the transmission lines with the LMP in the PJM market is proposed in [59]. This method is illustrated in Figure 10, as proposed in [60]. There is a redispatch of generators with the change in LMPs to alleviate congestion with a minimum cost of congestion. In this case, the congestion cost is reduced from 1000 USD to 600 USD with the new redispatch.

2.2.6. Distributed Generation (DG) Method for CM

Deregulation in the electricity market has brought congestion in the power system due to the overutilization of the existing transmission framework. Due to congestion, the voltage profile becomes degenerated. The employment of DG plays a crucial role in maintaining the voltage profile within the pre-defined limits for system stability. Distributed generators (DGs) help to reduce congestion by reducing the power flows through congested lines. With the advancement in technology, DG exploits the regional renewable resources in economical ways, hence obtaining generous profits that repay their invested capital and inspire an increased deployment of DG. To achieve maximum benefit and CM, DG must be placed at the optimal location. A real coded GA and NSGA II method is proposed in [61] for the optimal location and sizing of the DG. The DG play a crucial role in a very congested system with very high LMPs. The placement of DGs at such locations reduces the energy prizes as proposed in [62]. An LMP-based DG location is presented to enhance social welfare and the voltage profile [63]. Renewable energy-based DG placement is employed in the power system to mitigate congestion. A salp swarm algorithm (SSA) based on Artificial Intelligence (AI) is proposed in [64] to locate the wind power plant (WPP) as DG in the power system for CM. Sensitivity factors are very important in obtaining the location of the DG. Some of the sensitivity indices such as the voltage profile index [65,66], loss reduction index [67], environmental impact reduction index [68] and, DG index [69] are proposed in the literature. Increasing the system security by optimal DG placement using the difference between maximum LMP and LMP is proposed in [70]. A cost/worth analysis-based and flow gate marginal price-based method is proposed in [71,72] to place DG at the optimum location for CM. Energy storage systems and renewable energy resources (RES) are reported to charge and discharge to overcome the uncertainty of RES [73].

Figure 11 illustrates a case of congestion management by DG placement proposed in [74]. It can be observed that the total percentage loading on the congested lines (33–34, 20–33, 16–17, and 14–34) is reduced significantly to alleviate congestion in the system.

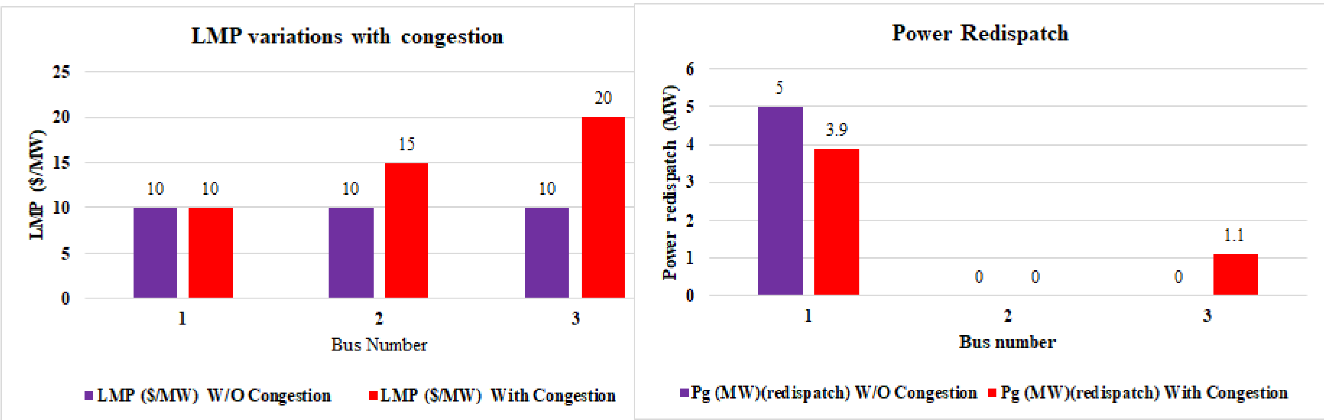

Figure 10. Illustration of CM by the nodal pricing method.

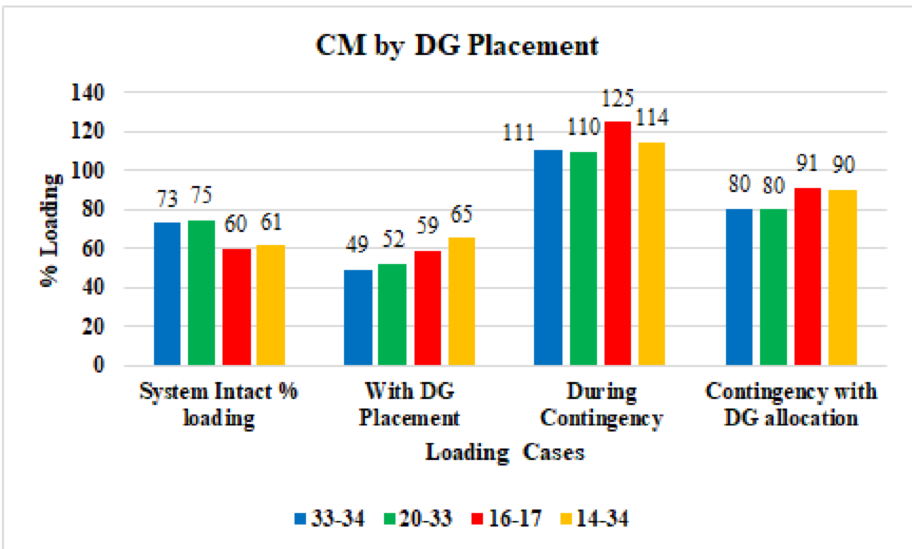

Figure 11. CM illustration by DG placement.

A brief comparison of different approaches for CM is shown in Table 2.

Table 2. A comparison between different CM approaches.

S No.	Approaches of CM	Type of CM	Advantages	Disadvantages
1	FACTS-based CM	Cost-free	Increases the power transfer capacity, stability, and controllability of the networks by series or shunt compensation.	Very costly, needs very precise adjustment of FACTS parameters, a very accurate location is to be determined.
2	Phase-shifting transformers	Cost-free	Increases the overall capacity of grids, reliable and economic power flow management.	Cannot increase the individual capacity of lines, works effectively under low congestion values.
3	Network reconfiguration	Cost-free	Reduces line losses, improves voltage profile, reduces peak demand reduction in overloading of distribution lines, reduces in environmental pollution and distribution systems.	The change in configuration of network results in altered node voltage, line currents and degree of unbalances. This also results in the level of distortion of the node voltage.
4	ATC-based CM	Cost-free	Fruitful for open market trading and maintain economic, reliable, and secure operation over a wide range of system conditions.	Power losses are increased with the increase in ATC.
5	Generator rescheduling-based CM	Non-cost-free	Efficient congestion mitigation is obtained, reduces the need of load curtailment.	Raises the operating cost of the system due to the out of merit generators are involved more than scheduled generators.
6	First-come, first-served (FCFS)- and pro-rata method-based CM	Non-cost-free	Beneficial to make long-term predictions, efficient and quick security assessment can be performed, advanced knowledge of trade volume can be obtained.	Makes the networks users economically incompetent in the usage of transmission services.
7	Auction-based methods	Non-cost-free		Auctions are responsible for the decline in costs. The auction-based method generally runs into system issues and complexities.
8	Load curtailment-based methods	Non-cost-free	An effective way for CM in networks with low capacity.	Load curtailment results in economic losses in the system.
9	NP-based CM	Non-cost-free	Decrease in total generation cost, enhanced flexibility in selecting power injection to alleviate congestion.	The composition of markets in the nodal pricing-based method is not quite accepted when employing bilateral transactions.
10	DG-based CM	Non-cost-free	Short circuit levels are increased, load losses change, voltage profiles change along the network, voltage transients will appear, congestions can appear in system branches, power quality and reliability may be affected.	Short circuit levels are increased, load losses change, voltage profiles change along the network, voltage transients will appear, power quality, and reliability may be affected.

3. Optimization Algorithms for CM

To manage congestion in the power system, the operator has to deal with a large number of non-linear power system equations. Thus, certain algorithms and optimization techniques are to be implemented to make the task much simpler and to obtain the solution closest to the ideal one. In the literature, several optimization techniques are suggested which can be classified as shown in Figure 12.

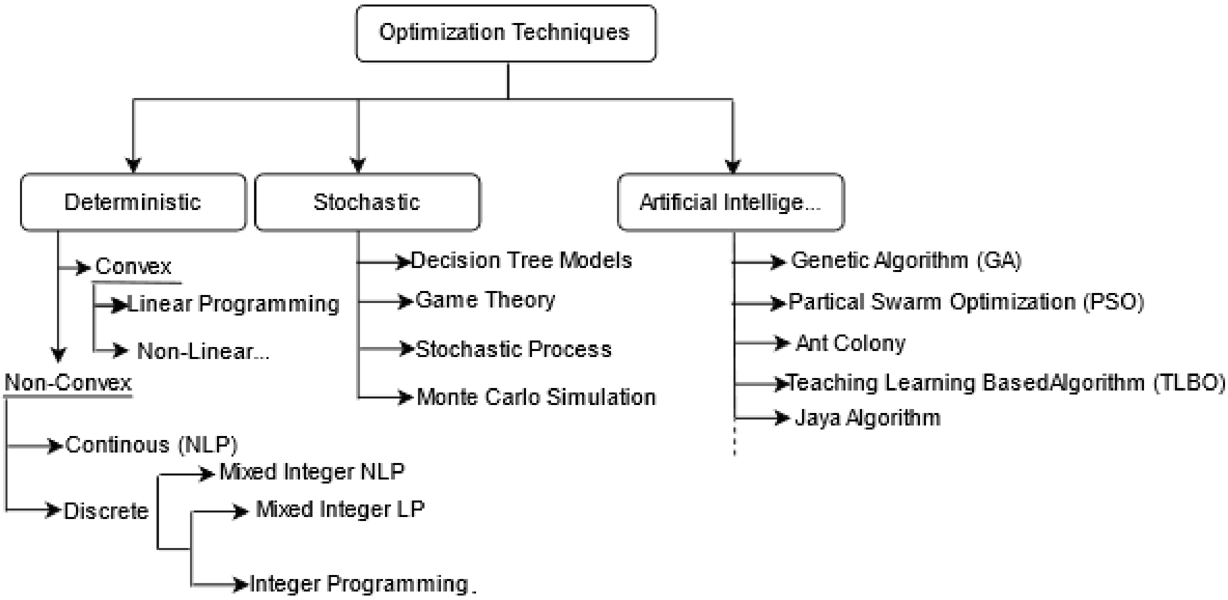

Figure 12. Classification of optimization techniques.

3.1. Genetic Algorithm (GA)

GA is one of the AI algorithms used widely by the researchers proposed in [75]. This algorithm uses the natural selection process to deal with constrained and unconstrained optimization problems. This algorithm selects the parents from the current population to generate the next generation and henceforth produce offspring nearer to the optimal solution. The pseudocode for the genetic algorithm can be given as follows (Algorithm 1):

Algorithms 1: GA

1: Initialize
    for random population Gm = 0 at t = 0;
    randomly create individuals in initial population p(t)
    Gm = population of n randomly generated individuals;
2: Evaluate Gm: Calculate fitness(j) for all j ∈ Gm;
3: **Do**
  Initiate iteration m = 0
4: **Copy**: Select $(1 - \gamma) \times$ n members of Gm and insert into Gm + 1;
5: **Crossover**: Select $\gamma \times$ n members of Gm;
do pairing;
  harvest offspring;
  add offspring into Gm + 1;
6: **Mutate**: Choose $\chi \times$ n members of Gm + 1;
    reverse a randomly chosen bit in each;
7: **Evaluate**: Gm + 1:
    calculate fitness(j) for all j ∈ Gm;
8: Increase the iteration counter m = m + 1;
if the termination criteria is not satisfied
    go to step 4
  else, return the best individual
end

Generator rescheduling for CM is proposed in [76] by reducing the active power rescheduled, hence reducing the cost of congestion by employing GA. LMP-based nodal price determination of each generator for all buses is proposed using GA [77]. GA-based optimal power flow (OPF) is implemented to locate UPFC in the congested system for CM [78]. To solve the constrained non-linear dynamic congestion management (DCM) problem, a real coded genetic algorithm (RCGA) is proposed in [79] for rescheduling the generators.

3.2. Particle Swarm Optimization (PSO)

PSO is one of the bio-inspired optimization algorithms which mimics the way a school of fish or birds swarm reaches the destination by maintaining the distance while traveling in a group. This is a very simple type of optimization method with a very small number of optimization-specific parameters. This efficient algorithm is proposed in [80]. The pseudocode for PSO can be given as (Algorithm 2):

Algorithm 2: PSO

1: Initialize:
  for swarm population with dimension d in S
2: Initialize:
  random particle location: n(j, d) = rand (n_{min}, n_{max}) and
  random velocity in S:v (j, d0) = rand (v_{min}, v_{max})
  end for
  particle j, best position P_{bj} = n_j
3: Apprise global best location of j: G_b
  if $P_{bj} < G_b$
    substitute $G_b = P_{bj}$
  end if
end for
4: Appraise each particle's best location in S
  if $n_j < P_{bj}$ then $P_{bj} = n_j$
  end if
5: Appraise particle velocity:

$$\begin{aligned} v_{(j,d)} = v_{(j,d)} + C_1{*}rnd(0,1) * \left\{P_{b(j,d)} - n_{(j,d)}\right\} \\ +C_1{*}rnd(0,1) * \left\{G_{bd} - n_{(j,d)}\right\} \end{aligned}$$

  also, the position,

$$m_{(j,d)} = m_{(j,d)} + v_{(j,d)}$$

6: Increase the iteration iter = iter + 1 till iter = $iter_{max}$.

Implementation of PSO in CM by generator rescheduling is proposed in [81–83]. A particle swarm optimization technique with improved time-varying acceleration coefficients (PSO-ITVAC) is proposed for active power rescheduling of generators to mitigate congestion [84]. Multi-objective particle swarm optimization (MOPSO) is proposed for alleviating overloads and reducing the cost of generation [85]. A method is proposed in [86] to tune PSSs parameters to relieve the congestion. Methods are proposed in the literature to hybrid other algorithms with PSO. A hybrid of GWO–PSO is proposed in [87], BOA–GWO–PSO is proposed in [88], an efficient hybrid PSO is proposed in [89] for mitigating transmission congestion. A PSOGSA–TVAC hybrid algorithm is proposed in [90] for CM in the DPS.

3.3. Grey Wolf Optimization (GWO)

GWO is the optimizer based on the social hierarchies and hunting behavior of grey wolves proposed in [91]. There are three hierarchies in the pack of grey wolves. The alfa wolf is the leader, the beta wolves are the first hierarchy, and delta wolves comprise the second level. The rest of the wolves are the omega wolves which follow the upper hierarchies. The hunting behavior of grey wolves is mimicked in this algorithm. The pseudocode for this optimizer can be given as follows (Algorithm 3):

Algorithm 3: GWO

1: Initialize
  GWO variables (a, A & C)
  population randomly, n
  iteration counter, itr = 0
2: Calculate the fitness of all wolves
 for
 three best locations as α, β, and γ
 evaluate 'a' by $a\ (\mathrm{itr}) = 2 * \mathrm{itr}_{\mathrm{current}}\left(\frac{2}{\mathrm{itr\_max}}\right)$
 appraise the vectors A and C by $\left.\begin{array}{c}\vec{A} = 2\vec{a} * \vec{r}_1 - \vec{a} \\ \vec{C} = 2 * \vec{r}_2\end{array}\right\}$
 calculate the position vectors of X_α, X_β, and X_γ

end for
if
  position vectors X_α, X_β, and X_γ give a better fitness than previous
 while: itr < itr_max
 return: the best fitness, X_α
else,
  advance the itr count, itr + 1
end if
go to step 2

GWO being simple to implement with a smaller number of optimizer-specific parameters is proposed for CM in the literature by several authors. GWO is implemented in the power system in [92] to reduce the active power loss in different components of the power system. The TCSC parameter is optimized by applying GWO in [93]. Optimal load shedding for CM is achieved by employing GWO [94]. Optimization of the size of DGs using GWO is presented in [95] for a simultaneous reduction in voltage deviation, cost, and power loss in the system for CM. A hybrid of GWO with other algorithms is proposed in the literature for employing the advantages of both parent algorithms to optimize the objective function. A hybrid of Nelder–Mead–GWO is proposed in [96], and Grasshopper optimization (GHO)–GWO is proposed in [97].

3.4. Teaching Learning-Based Optimization (TLBO)

This is an efficient parameter-less optimizer used for mitigating congestion in the DPS. This algorithm is based on teacher–student relations in a class for communicating information. This algorithm is divided into two phases: the 'teacher phase' and the 'learner phase.' In the teacher phase, the information is transferred by a teacher only, while in the learner phase, the information is passed by the best students among students. This algorithm is proposed in [98]. The pseudocode for the TLBO algorithm is presented below (Algorithm 4):

The implementation of TLBO for limiting active power rescheduled in congested power systems by generator rescheduling is proposed in [99–101]. Optimization of the cost of operating a virtual power plant (VPP) using TLBO is proposed in [102]. CM by ATC enhancement is proposed by implementing TLBO in [103]. Certain hybrid algorithm with TLBO is proposed to relieve congestion in the power system. A hybrid of TLBO and PSO is proposed in [104]. An improved TLBO is proposed in [105] to mitigate congestion by integrating solar photovoltaic systems.

Algorithm 4: TLBO

1: Initialize learner population, Np in dimension D;
2: Evaluate learners
3: **While the** termination condition is not true
    select best learner, $X_{teacher}$ & find the mean of the rest of the learners, X_{mean}
4: **For** individual learner
    'Teacher Phase'
    $T_f = \text{round}\ (1 + \text{rand}\ (0, 1));$
    appraise learner by $X_{j,n} = X_{j,o} + \text{rand} * (X_{teacher} - T_f * X_{mean})$
    calculate newlearner $X_{j,n}$
    keep $X_{j,n}$ if : $X_{j,n}$ is better than $X_{j,o}$
    'Learner Phase'
    Randomly select another learner, $\mathbf{X_i}$ different from $\mathbf{X_j}$.
    appraise learner by $X_{j,n} = \begin{cases} X_{j,o} + \text{rand}*(X_j - X_i), & \text{if } f_{xj} \le f_{xi} \\ X_{j,o} + \text{rand}*(X_i - X_j), & \text{if } f_{xj} > f_{xi} \end{cases}$
    calculate $X_{j,n}$
    return: if $X_{j,n}$ is better than $X_{j,o}$

end for
end while

3.5. JAYA Algorithm (JAYA)

The JAYA algorithm a strong and efficient algorithm applied for optimizing both constrained and unconstrained non-linear system problems. The uniqueness of this algorithm is that it is a parameter-free algorithm and, hence, no initial parameters are required for initialization. This algorithm works to move the solution towards the best solution from the worst solution of the optimization problem. It can be used for both maximization or minimization of a given objective function. The JAYA algorithm is proposed in [106]. The pseudocode for the JAYA algorithm can be written as follows (Algorithm 5):

Algorithm 5: JAYA

//Initialize population size, p; maximum iteration, itr_max & design variables, I;
1: Randomly select the best fitness candidate and worst fitness candidate
2: Appraise the fitness value of the candidate by

$$X^{t+1}_{ji,itr} = X^t_{ji} + \text{rand}_1\left(X^t_{cb} - \left|X^t_{ji}\right|\right) - \text{rand}_2\left(X^t_{cb} - \left|X^t_{ji}\right|\right)$$

3: Ff $X^{t+1}_{ji,itr}$ is a better candidate solution then $\mathbf{X^t_{ji}}$
    update the new solution
else, consider the previous solution
if the termination criteria satisfied
Return: consider the solution as optimum
else, go to step 2

The JAYA algorithm for implementing the DG in the congested network to reduce the generation cost and power loss and enhance the voltage stability of the system is proposed in [107]. CM is achieved by demand response (DR) and optimal transmission switching (OTS) for a system by implementing conventional and RES generators using the JAYA algorithm [108]. For reducing the power loss and enhancing the loadability of the system, an Elitist–Jaya (IEJAYA) algorithm is proposed in [109]. A modified JAYA (MJAYA) algorithm is proposed in [110] to reduce the active power loss to mitigate congestion. A self-adaptive Lévy flight-based Jaya algorithm for optimally placing the DG in a congested system is proposed in [111] to minimize voltage deviation and CM. Apart from the mentioned meta-heuristic optimization algorithms, there are other algorithms such as ant lion optimization (ALO) [112], the firefly algorithm (FA) [113], the gravitational search algorithm (GSA) [114], the honey bee algorithm (HBA) [115], etc.

Constraints for different optimization techniques detailed above are shown in Table 3.

Table 3. Constraints for different optimization techniques.

S No	Optimization Techniques	Constraints/Parameters
1	GA	Population size, number of generations, crossover rate, mutation rate, length of block swap over between parents and off-springs.
2	GWO	Population size.
3	PSO	Problem dimension, number of particles, acceleration coefficients, inertia weight, neighborhood size, number of iterations, random values scaling depending on cognitive and social components.
4	TLBO	Number of dimensions, lower bound, upper bound, number of particles and maximum number of iterations.
5	JAYA	Population size, maximum number of iterations, random values of two random variables between 0 and 1.

A summary of previous work undertaken on congestion management is given in Table 4.

Table 4. Summary of the literature on congestion management.

Author Name and Publication Year	Work Undertaken in Paper	Objective Function	Limitations Observed in the Method Applied
Kaltenbach J C, Peschon J, 1970 [116]	A computational method-based approach is proposed, optimally merging the previously separated load flow calculations, reliability scrutiny, and economic calculations. This procedure is validated on a 17-node system so that the disturbances in heavily loaded lines may not affect the rest of the system.	The function includes the following: • Economies of scale; • Reliability; • Nonmonotonic growth of the node injections.	The results obtained by the 17-node system, which has been tested here, cannot be implemented for a different standard system, authenticated by technical societies.
Carson T, Guy S, Adel H, 1994 [117]	The modeling of SVC is described as a standard for electrical utility industries. Apart from transient stability program modeling, long-term dynamic programming is described.	The main objective of this paper is to recommend a standardized model of SVCs. Modelling of transient stability programs and long-time dynamic stability programs are also recommended.	The guidelines given for the correct use of models in power flow programs are not suitable and practical for expanding power systems with increased load demand.

Table 4. *Cont.*

Author Name and Publication Year	Work Undertaken in Paper	Objective Function	Limitations Observed in the Method Applied
Reddy, K.R.S.; Padhy, N.P.; Patel, R.N.N, 2006 [118]	The FACTS device, TCSC and UPFC, is located by LMP difference congestion rent contribution methodologies for mitigating congestion. IEEE 14, 30, and 57 bus systems are used as test systems.	• Social welfare $C_{fg} = \prod NL\ line = 1\ OVl_{line}$ • C_{fg} is the configuration of FACTS device with penalty for overloading of lines	The congestion is mitigated by using LMP and congestion rent methods. With the enhanced complexity of the power system, the proposed technique becomes very inefficient and the location of the device obtained is not optimal.
Gitizadeh, M., Kalantar, M., 2008 [119]	TCSC and SVC are used to avoid congestion. GA, fuzzy, and sequential quadratic programming are used to obtain the optimal location of FACTS devices. Results validated on the IEEE14 bus system. The objective function is to enhance the voltage stability margin and security margin of the system.	The objective function includes the following: • $f_1 = N_{FACTS}$ • $f_2 = 1 - SM = \frac{\sum_{j\in JL} S_j^{initial}}{\sum_{j\in JL} S_j^{limit}}$ • $f_3 = \sum\limits_{i\in J_L} VD_i = \sum\limits_{i\in J_L} \frac{\varnothing\left(\left\lvert V_i - V_i^{ideal}\right\rvert - dV_i\right)}{V_i}$	The algorithm is tested only tested on a small non-complex system and is not validated on a higher-order system. When the location of FACTS is to be optimized for a higher-order system, some alterations are to be undertaken.
Hashemzadeh H and Hosseini S H, 2009 [120]	PSO is implemented for locating TCSC to mitigate congestion in the power system by minimizing the cost of congestion and net generation cost.	In this paper, the reduction of total congestion cost and generation cost are the objective functions: $TCC = \sum\limits_{ij=1}^{NL} \Delta\rho_{ij} * P_{ij}$, where $\Delta\rho_{ij}$ is the difference in LMPs.	Here, line outage sensitivity factors using the DC power flow method are used to reduce the search space of PSO. This method is suitable for small systems only. In the case of complex systems, the errors due to DC power flow cannot be computed effectively.
Mandala M, Gupta C P, 2010 [121]	TCSC is used for reducing transmission losses and generation costs while increasing the loadability of lines with increased stability of the system. The real power performance index (PPI) is the base for the optimal location of TCSC to mitigate congestion. Three locations are obtained by PPI and the optimized location is decided by minimizing production cost using interior-point methods.	This paper includes objective to perform cost benefit analysis of TCSC as $C_{TCSC}(k) = c * x_c(k) * P_L^2$ $minP_i \sum\limits_i C_i(P_i) + C_{TCSC}$ • The TCSC location is the place with the most positive PPI	In large and complex systems, the location of FACTS devices by utilizing sensitivity factors produces an error in the location prediction, unless a penalty factor is incorporated. Here, no such factors are implemented.
Vijayakumar K., 2011 [122]	TCSC and UPFC are placed to relieve congestion in IEEE 57 bus system. The location is optimized using GA.	The objective of research is to maximize social welfare with enhance system security: $min\left(\sum\limits_{i=1}^{NG} C_{Gi}(P_{Gi}) - \sum\limits_{i=1}^{NG} B_{Di}(P_{Di})\right) \forall T_{ij} > 0$ T_{ij}: bilateral transaction between supplier i and consumer j.	Only the technical benefits of TCSC and UPFC are considered here in terms of the loadability of the line. The economical criteria are not considered here. Social welfare maximization and line overloading problems are solved separately in this paper. The two may be considered simultaneously by using other optimization methods.

Table 4. *Cont.*

Author Name and Publication Year	Work Undertaken in Paper	Objective Function	Limitations Observed in the Method Applied
Anwar N, Siddiqui A S, and Umar A, 2012 [123]	FACTS together with power oscillation damper (POD) are implemented here for compensating voltage. UPFC is found to be more suitable for decongesting the bus as compared to SSSC.	The power flow is enhanced to alleviate congestion by using POD with SSSC with function as $H(s) = K\left(\frac{1}{1+sT_m}\right)\left(\frac{sT_w}{1+sT_w}\right)\left(\frac{1+sT_{lead}}{1+sT_{lag}}\right)^{m_c}$ T_m: measured time constant; T_w: washout time constant; T_{lead}, T_{lag}: lead and lag time constants.	UPFC is quite a costly installation as compared to SSSC. Moreover, it is used with POD which makes the combination not suitable for social welfare. Thus, economic consideration makes this method not appropriate for decongesting the system.
Ashwani K, Charan S., 2013 [124]	The third generation of FACTS device, STATCOM, is used in this paper. Its effect on the optimal rescheduling of generators is studied for reducing the congestion cost. Security margin and voltage limits are used here to implement three bid block assemblies.	This paper objective function includes the reduction of fuel cost with the impact of FACTS device on generator rescheduling. $\min obj = \sum_{i=1}^{ng}\sum_{k=1}^{24} a(i)\left(c(i)\left(\sum_{t=1}^{t\ max} P_{g(i,t,k)}\right)^2 + b(i)\sum_{t=1}^{t\ max} P_{g(i,t,k)} + a(i)\right)$	The method applied here gives the most economical congestion costing only when the rescheduling is performed with the incorporation of renewable energy systems.
Siddiqui, A.S., Deb, T, 2014 [125]	This paper investigates the effect of SVC, TCSC, and UPFC devices on power flows and bus voltages with increased line loadings. IEEE 14 bus system is tested.	Static modelling of SVC, TCSC and UPFC is undertaken. Under 30% overload condition in steps of 10% increment, the effect of implementation of FACTS devices is validated on IEEE-14 bus system and WSCC 9 bus system.	In this paper, all three devices are used. The series device improved line flow, the shunt device improved the voltage profile, and the series shunt device UPFC managed both. No special method for location was adopted.
Singh J G, Singh S N, and Srivastava S C, 2016 [126]	The location of UPFC is determined here by using "PTCDFUs" as the sensitivity factor. The results are validated on the Indian 75 bus system and the new England 39 bus system for CM.	The optimal power flow is formulated to minimize the cost function for generator rescheduling. $\min \sum_{i=1}^{N_G} C_{Pi}(\Delta P_{Gi})\Delta P_{Gi}$ $C_{Pi}(\Delta P_{Gi})$: bid function; ΔP_{Gi}: active power rescheduled.	The congestion cost is reduced and the active power rescheduled is quite low. However, the paper concludes that if the cost of UPFC is considered, this method is not suitable for application.
Gupta S K, N. Yadav K, and Kumar M, 2018 [127]	In this paper, IPFC, UPFC, and HVDC are used with generator rescheduling to obtain the congestion cost in the standard IEEE 30 bus system. Here, congestion cost with IPFC becomes less as compared to the other FACTS incorporated.	The objective is to minimize the congestion cost together with the implementation of FACTS. $minCC = \sum_{r=1}^{Ng,up} C^{+}_{Pgr}\Delta P^{+}_{gr} + \sum_{s=1}^{Ng,dn} C^{-}_{Pgs}\Delta P^{-}_{gs} + \sum_{t=1}^{Ncl} C_{Pdt}\Delta P_{Dt} + \sum_{v=1}^{Nqg} C_{Qgv}(\Delta Q_{gv})\Delta Q_{gv}$	Generator rescheduling itself is a method of congestion management that includes the cost of rescheduling. Here, this rescheduling is undertaken with the FACTS device. IPFC is a very costly device, which makes the system extremely costly.
Farahani V Z and Kazemi A, 2006 [128]	Cost-free and non-cost-free methods are compared to mitigate congestion. Generator rescheduling and load curtailment are compared with the application of FACTS devices for congestion management.	Two objectives are used here for managing congestion. The first is bilateral dispatch with a load curtailment strategy and the second is bilateral dispatch with FACTS devices: $minf(x,u) = \sum_{i=2}^{m}\sum_{j=m+1}^{n} W_{ij}\left(T_{ij} - T^0_{ij}\right)^2$ W_{ij} is the willingness to pay factor; T^0_{ij} is the desired value of transaction T_{ij}.	The two methods are compared and both methods are found effective. Only TCSC is applied and compared. The comparison with other FACTS devices may discriminate the effective method.

Table 4. *Cont.*

Author Name and Publication Year	Work Undertaken in Paper	Objective Function	Limitations Observed in the Method Applied
Mohd Isa A Niimura T, Yokoyama R, 2008 [129]	Physical transmission congestion is relieved by curtailing a small portion of the non-firm transactions. The system operator can select the most effective and desirable congestion relief measures.	The objective here is to maximize the total social welfare by maximizing the difference between total supplier cost and total consumer benefit. $\max TSW = \sum_{i=1}^{ND} \left(d_i P_{di}^2 + e_i P_{di} + f_i\right) - \sum_{i=1}^{ND} \left(d_i P_{di}^2 + e_i P_{di} + f_i\right)$	Load curtailment is applied together with generator dispatch for mitigating congestion. Generator rescheduling cost is not considered. This makes the system uneconomical.
Hazra J, Sinha A K, Phulpin Y, 2009 [130]	In this paper generator re-scheduling and load shedding are presented for CM using the ratio of current concerning bus change injected parameters as a sensitivity factor.	The objective here is to minimize the cost of generation and to minimize the overload. $L_{shd,k}$ is the amount of load shedding at bus k; p_i, q_i, r_i are the cost coefficient of generator; and p'_k, q'_k, r'_k are the cost coefficient of load shedding at bus k. $F_1 = \sum_{i=1}^{NG} \left(p_i + q_i P_{gi} + r_i P_{gi}^2\right) + \lvert e_i * sin\left(f_i * \left(P_{gi} - P_{min}\right)\right)\rvert + \sum_{k=1}^{PL} \left(p'_k + q'_k L_{shd,k} + r'_k L_{shd,k}^2\right)$	Load curtailment is a non-cost-free method for CM. Here, only generator rescheduling is not mitigating congestion, but load curtailment has to be performed. This makes the process uneconomical.
Verma S, Mukherjee V, 2016 [131]	In this paper generator rescheduling for active power output is proposed by implementing the firefly algorithm (FFA) for CM. The method is applied in the pool-energy market to reduce the congestion cost.	The objective of this paper is to reduce congestion cost by rescheduling generators while satisfying the constraints. $C_c = \sum_{j \in Ng} \left(C_k \Delta P_{Gj}^{+} + D_k \Delta P_{Gj}^{-}\right)$ C_c, C_k, and D_k are the cost incurred in rescheduling active power output.	Use of sensitivity factors for the selection of participating generators along with rescheduling may be used instead of only applying FFA.
Chintam J, Daniel M, 2018 [132]	This paper proposes a satin bowerbird optimization (SBO) algorithm to mitigate congestion in the DPS. A generator rescheduling-based approach is applied to mitigate congestion.	This paper presents a satin bowerbird optimization (SBO) algorithm to minimize the active power rescheduled to mitigate congestion with the following objective function: $CC = \sum_{j \in NG} \left(C_{kG} \Delta P_{Gj}^{+} + D_{kG} \Delta P_{Gj}^{-}\right) \$/h$ CC, C_{kG}, and D_{kG} are the cost occurred in rescheduling active power.	From the single-objective and multi-objective cases, it can be observed that the objectives are antagonistic, i.e., adversely affect each other during optimizing. The method may be updated to resolve this problem.
Entezariharsini A, Ghias I S., Mehrjerdi 2018 [133]	Effects of wind on energy market parameters are studied in this paper. This paper addresses the location and penetration of multi-wind turbines in the power system. Flow-gate marginal pricing (FMP) is examined for a different siting of wind power plants, numbers, and ratings.	The objective of this paper is to minimize the annual operational cost of the generators in the network. The objective function is modeled as $C^p = \sum_{s \in S} \sum_{g \epsilon G} \sum_{t \in T} \left\{ \left(P_{s.g.t} * C_{g,t}^{v} + C_{g,t}^{f} \right) * P_s * 365 \right\}$	The effect of multiple wind turbines on the system is explored. Several FMPs are made on the high voltage side of the network and no FMP on the lower voltage side. The higher number of FMP is undesirable and has to be examined.

Table 4. *Cont.*

Author Name and Publication Year	Work Undertaken in Paper	Objective Function	Limitations Observed in the Method Applied
Satish K., Ashwani K. 2020 [134]	FACTS devices are implemented here for optimal balancing of different types of loads together with a high penetration of wind power to mitigate congestion. To maintain voltage within limits, different FACTS devices are compared for their performance in achieving the optimized solution of the objective function.	Design of bilateral and hybrid electricity market is discussed. Design of STATCOM, UPFC, SSSC, IPFC and GUPFC is proposed. Sensitivity-based approach for determining the optimal location of FACTS devices is proposed. Impact of different levels of wind power integration is validated and its effect on congestion is detailed.	In this paper, a sensitivity factor-based approach for congestion minimization is presented and implemented for wing-integrated systems (WIS). Induction generators are used in wind turbines, which are consumers of reactive power. To compensate for this power additional FACTS devices are implemented, making the system very costly.
Nico B., Tarek AlS K., Wilfried V. S. 2020 [135]	This paper presents an analysis of charging transactions of EVs on a Netherland-based EV company. Different scenarios are proposed to create future charging transaction data based on the data for the previous transactions. This paper concludes that with the larger implementation of shared EVs as ancillary services, the charging demand peaks are reduced, in turn reducing the congestion in the system.	• In this paper the historical charging data for EVs is taken, compared with present data and then a novel method to generate a future set of data of EV charging transactions is proposed. • The paper presents the future grid congestion with a high adoption of shared EVs.	This study compares the charging patterns of regular and shared EVs and creates insight into the grid impact and potential to provide ancillary services with the future adoption of shared EVs. Charging optimization methods are not applied to shared vehicles for adopting them as future ancillary services.

4. Conclusions

In the current DPS, there is a dire need to use the available resources optimally. Due to deregulation policies, the CM has become a crucial problem. Make system congestion free must be the target, so that the system works optimally under constrained conditions. Hence, this paper provides a comprehensive review on different methods to mitigate congestion in the DPS. The classical and the non-conventional methods are reviewed comprehensively facilitate research for new authors working in the field of CM. Different methods to mitigate congestion, such as the application of FACTS devices, generator rescheduling, load curtailment, ATC enhancement, implementation of DGs and electrical vehicles, are reviewed. Different nature-based optimization algorithms, such as GWO, GA, PSO, TLBO and JAYA algorithms, are presented with their respective pseudocodes. The application of these optimizers in CM is reviewed for different test systems. The application of RES in the congested system is presented. It can be concluded that, at present, the RES- and DG-based CM together with FACTS devices are the most efficient CM methods.

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Nomenclature

DPS	Deregulated power system
EPS	Electrical power system
GENCOS	Generation companies
TRANSCOS	Transmission companies
DISCOS	Distribution companies
PX	Power exchangers
ISO	Independent system operator
TSO	transmission system operator
CM	Congestion management
FACTS	Flexible alternating current transmission systems
ATC	Available transfer capability
TTC	Total transfer capacity
TRM	Transmission reliability margin
ETC	Existing transmission commitment
CBM	Capacity benefit margin
P	Active power
Q	Reactive power
GTO	Gate turn off thyristor
PST	Phase shifting transformer
DT	Dynamic tariff
WG	Wind generator
TCDF	Transmission congestion distribution factor
PTDF	Power transmission distribution factor
GR	Generator rescheduling
LC	Load curtailment
RED	Relative electrical distance
GSF	Generator sensitivity factor
FCFS	First come first serve
LMP	Locational marginal price
NP	Nodal pricing
DG	Distributed generation
WPP	Wind power plant
RES	Renewable energy resources
AI	Artificial Intelligence
GA	Genetic algorithm
GWO	Grey wolf algorithm
PSO	Particle swarm optimization
TLBO	Teaching learning-based algorithm
DR	Demand response
OTS	Optimal transmission switching

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