Al-Furat Journal of Innovations in Electronics and Computer Engineering (FJIECE)
ISSN -2708-3985

Hybrid Optimal Power System Recovery and Load Pick-Up With DG Allocation In Electrical Power System

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https://doi.org/10.46649/fjiece.v3.2.33a.12.6.2024

Abstract. *The increasing demand for electricity, the expansion of complex power networks, and the operation of power systems near their capacity have heightened the risk of power outages. Consequently, control room operators must develop comprehensive restoration plans to minimize recovery time. Key steps in power system restoration include starting non-black-start units with black-start units and initiating load pick-up. This process requires identifying the shortest route between nodes to expedite repairs. This research presents an expert plan employing the Modified Cuckoo Search algorithm (MCSA) to determine optimal pathways. Additionally, it explores the optimal allocation of distributed generators (DG) to enhance the system's voltage profile and reduce power losses using particle swarm optimization (PSO). The results demonstrate that DG significantly reduces losses during recovery. The study prioritizes the restoration of DGs with strong black start capability, considering network and DG constraints. The effectiveness of the proposed restoration approach is validated through MATLAB simulations on the IEEE 39-bus system.*

Keywords: Blackout Recovery; Shortest path; Load pick-up; MCSA technique; Generator Capability Curve; Graph theory; distributed generation (DG).

INTRODUCTION

Complexity caused decision-making issues in restoring the power system (PSR). Every power outage is different. Every restoration has similar goals and steps. The first requirements define two generator categories: Black-Start (BS) hydro and gas generators can start themselves. Steam turbines and other non-black-start (NBS) devices require external power to start[1] . PSR begins with a period of careful planning, when time is critical and various urgent actions need to be carried out right away. The typical procedure comprises evaluating the state of the system through a blackout, identifying the particular system that needs to be restored, planning the reconstruction of the transmission network, locating the initial power source, and putting policies in place to supply power to the NBS generators and critical loads by established pathways. It is important to carefully plan steps for quick action during the critical restoration period [2]. BS generators can restart without cranking power, unlike NBS generators. To guide the restoration of lines connecting base stations and non-black start units, these resources must be carefully managed and line recovery procedures established. This will allow NBS units to contribute to system recovery and achieve BS unit cranking power. A typical black start operation involves demand restoration, system restoration, and system preparation. System preparation involves assessing the system state and planning the black start procedure. System restoration requires turning on BS generators to power gearbox lines and NBS units.

Restarting loads with repaired generators is the final step in load restoration [3]. Some non-black-start components, such as traditional synchronous electrical generators or renewable energy sources, can receive initial power from the reestablished network during reconfiguration, but most are too long to be seamlessly integrated or synchronized by the grid. To clarify, non-black-start devices are dormant until the cranking period after receiving the cranking power supplies. After load restoration, non-black-start units, including renewable power units, are added one by one. The distinction between network reconfiguration and load restoration is often blurred or absent due to power outages' severity[4]. Ensuring the ongoing functioning of a separate sector of the electricity system may help reduce harm to customers. While users may be disconnected during the first interruption, shortening the duration of the local outage has major advantages. Distribution islands may become more resilient as a result of the growing usage of distributed energy resources (DERs) [5].

Because multiple renewable sources are distributed widely, there are operational issues. Complexity is increased by the uncertain and weather-related supply of energy from sources like solar and wind power, which exposes a distribution system operator (DSO) to a greater variety of potential scenarios [6]. The extended BS pathways are found using the Dijkstra algorithm. But the conventional bulk power grid which is connected to Distributed Generators (DGs) is the focus of this analysis[7].

The network has sufficient strength and stability to withstand brief power outages brought on by a rise in demand and the installation of big generating units. The device automatically opens all circuit breakers in the blackout zone prior to the restoration operation. In order to transfer the power source to the transmission lines using this manner, a challenging switching operation is needed [8].

Numerous restoration techniques after a blackout are documented in the literature. One method for determining a node's relevance is the node contraction technique [9]. Grid reconfiguration efficiency is the optimization target and the ideal skeleton networks are constructed using a discrete particle swarm. The power system's hierarchical scheduling requirements are met by the hierarchical collaborative optimization method. The goals are outlined as achieving grid reorganization and reaching complete power production [10]. In addition to this research focusing on a specific stage of healing, comprehensive approaches have also been suggested. A comprehensive sequential structure was suggested[11].

Scholars have made efforts to create new models and approaches to deal with the most important part of the restoration problem, which is determining the optimal generation start-up sequence. An ant colony optimization method for figuring out the best order to start a generator in while restoring a bulk power system is described in [12]. By considering the characteristics of different generation units, these authors goal is to maximize the system's producing capacity throughout the restoration process. Explored the most efficient method for restoring the skeleton network, taking into account the sequence in which generators are started and the process of picking up the load. After constructing a backbone network using online generators, it is important to establish the load pick-up sequence. This should be done while ensuring system stability and avoiding any technical constraint infractions, as the system isn't as resilient as it is under normal conditions[13].

This paper outlines a detailed strategic plan, which includes pre-established processes, to aid engineers in the control room in effectively and securely managing the process of recovery after a total power failure. The computational method was used to tackle the problem of creating a sequence of BS generators, with the goal of speeding up the recovery time and load pick-up with maximizing the system's generation capability. MCSA is used to determine the optimal pathways for restoring power in a grid, reducing the time and effort required for recovery and improving the overall efficiency of the restoration process, apple on the modified IEEE 39-bus test system. Emphasis was placed on restoring Distributed Generators (DGs) with robust black start capability, while taking into account the constraints imposed by both the DGs and the network.

MODIFIED CUCKOO SEARCH ALGORITHM (MCSA)

a) Graph theory is a branch of data structure that specifically deals with the representation of networks and the measurement of their characteristics. A graph may be used to depict the implementation of the transmission network. A graph (G) is a data structure that has vertices, representing points, and edges, which connect these points. Graphs may be broadly classified into two categories: directed graphs and undirected graphs. Each of these edges has the ability to be either weighted or not weighted. In equation 1, the vertices (V) & edges (E) are present, and each has a weight (W).

$$G = (V,E,W) \tag{1}$$

b) The Modified Cuckoo Search algorithm (MCSA) is an enhanced version of the cuckoo search algorithm that outperforms the cuckoo search (CS), Particle Swarm Optimization (PSO) and Differential Evolution (DE) algorithms. When working with MCSAs, there are two parameters that need to be adjusted: the population size (n) and the probability of diversity (Pd)[14]. After setting the value of n, the parameter Pd is responsible for controlling elitism, which requires adjustment. Because of the limited quantity .The modified cuckoo search algorithm is characterized by a reduced level of complexity and a higher level of generality in terms of parameters. Two modifications are implemented in the modified version of the cuckoo search algorithm (CSA). The initial adjustment is applied to the Lévy flight step size α. In the context of CSA, the value of α is fixed at 1 and remains constant. However, in MCSA, as the number of generations increases, the value of α is systematically decreased. Within the MCSA, a subset of eggs exhibiting superior fitness (i.e., quality) is selected and designated as the top eggs. At first, the value of the Lévy fly step size A was set to 1. In each generation, a new value of the Lévy flight step size was determined using the formula $\alpha = A/\sqrt{G}$, where G represents the generation number. This exploration search is conducted exclusively on a subset of nests that are expected to be abandoned. Both the cuckoo search and modified cuckoo search algorithms use random stage sizes[14], as seen in Figure 1.

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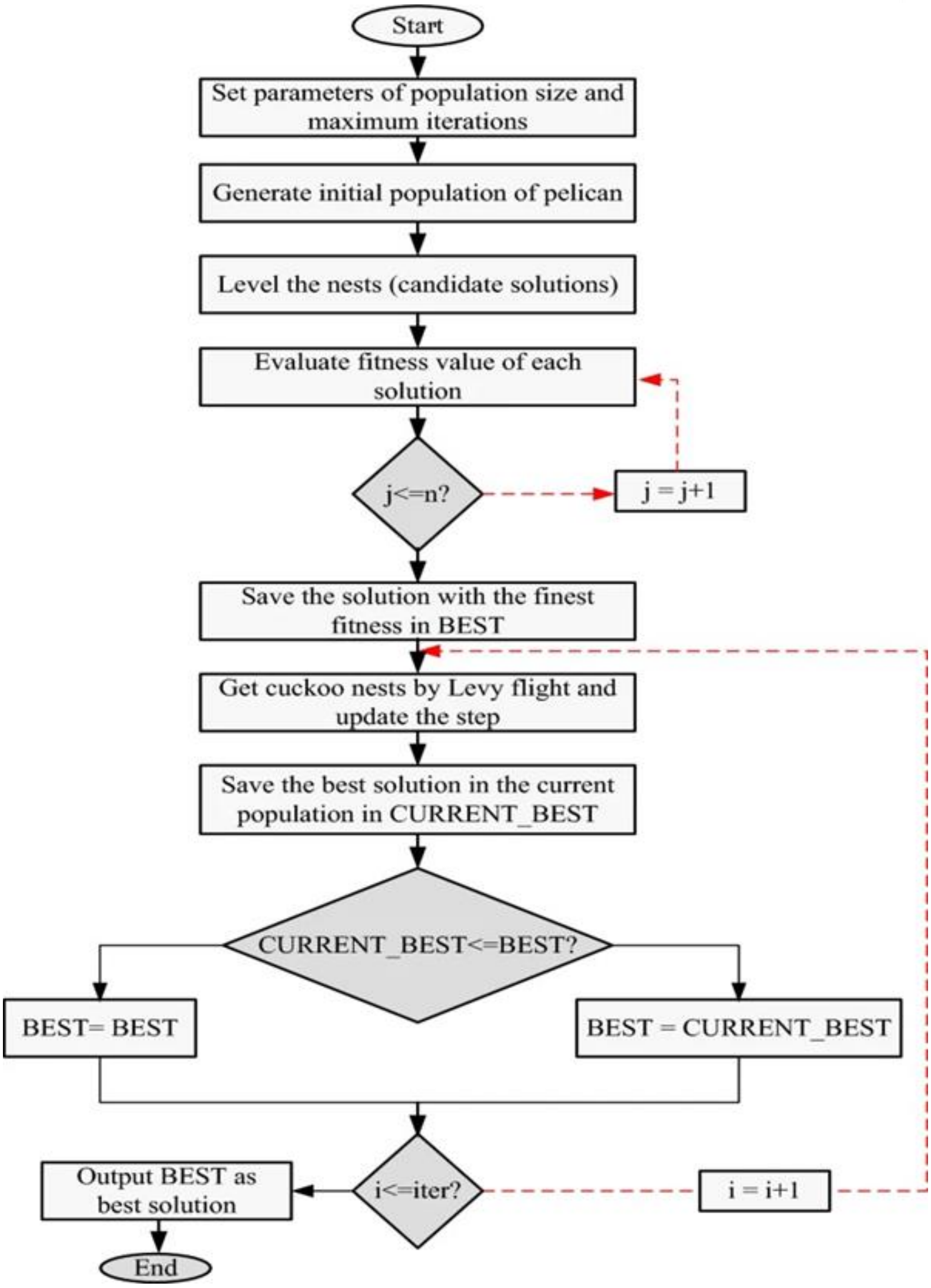

Fig. 1. Flowchart of Modified Cuckoo Search algorithm (MCSA)

DG TECHNOLOGIES

The DG technologies were classified under the following four groups[15]:

Category 1: The system is capable of solely accepting active electricity from distributed generation sources, such as photovoltaic (PV) systems, fuel cells, and micro turbines.

Category 2: The system has the capability to simultaneously receive both active and reactive power. Double fed induction powered generators (DFIG) utilized in wind turbines and synchronous generators are both instances of category 2 distributed generators (DGs).

Category 3: The system is solely capable of receiving reactive power. Synchronous compensators, often known as gas turbines, are the distributed generators (DGs) in this particular category.

Category 4: It consumes reactive power from the electrical system in order to generate active power. The wind turbines found in wind farms serve as an example of Category 4 Distributed Generation (DG). Fig. 2 depicts a standard power system model that includes diesel-generation (DG) sources.

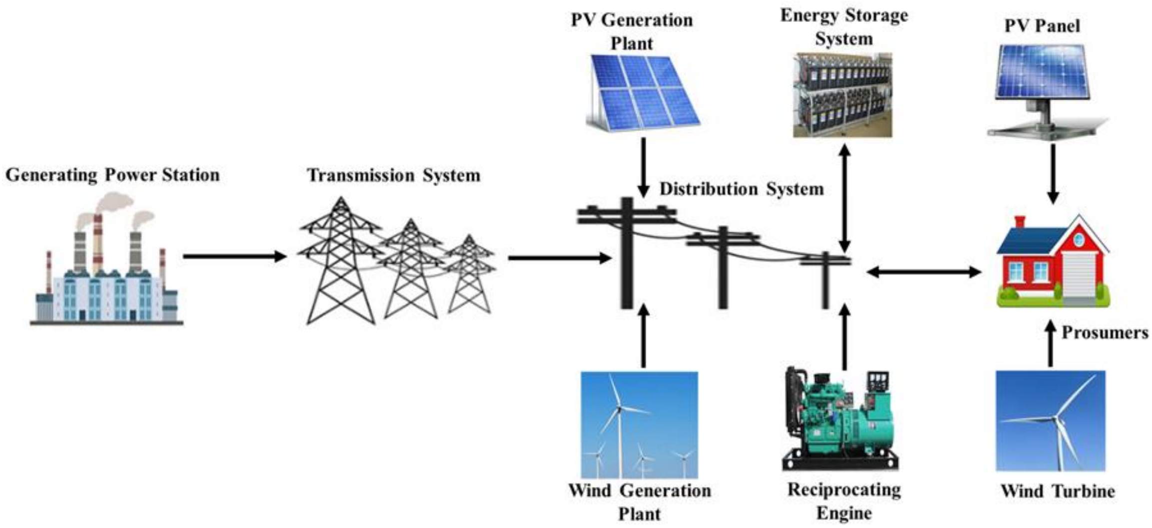

Fig.2. Conventional power system model using distributed generation (DG) sources

PARTICLE SWARM OPTIMIZATION (PSO)

In 1995, Kennedy and Eberhart introduced the Particle Swarm Optimization (PSO) method as a population-based tool for enhancing performance. The behavior seen in bird flocking or fish schooling acts as a muse. PSO is a optimization technology that relies on a search algorithm based on population dynamics. In this strategy, discrete particles undergo changes in their location or condition over time. Particle Swarm Optimization is a computational method that involves the movement of particles inside a multidimensional search space. During flight, each particle changes its location based on its own experience (Pbest) and the experience of a neighboring particle (Gbest). This entails using the most advantageous position that is shared by both parties, as seen in Figure 3. The concept of velocity may be used to express this change. The provided equation allows for the modification of the velocity of each agent [16].

$$V_{id}^{n+1} = \omega v_{id}^{n} + [C_1 rand \times (pbest_{id} - S_{id}^{n})] + [C_2 rand \times (gbest_{d} - S_{id}^{n})] \quad (2)$$

The given equation may be used to modify the current position in order to search for a place inside the solution space.

$$s_{id}^{n+1} = s_{id}^{n} + v_{id}^{n+1} \quad , i = 1,2 \ldots k, \;\; d = 1,2\ldots\ldots m \quad (3)$$

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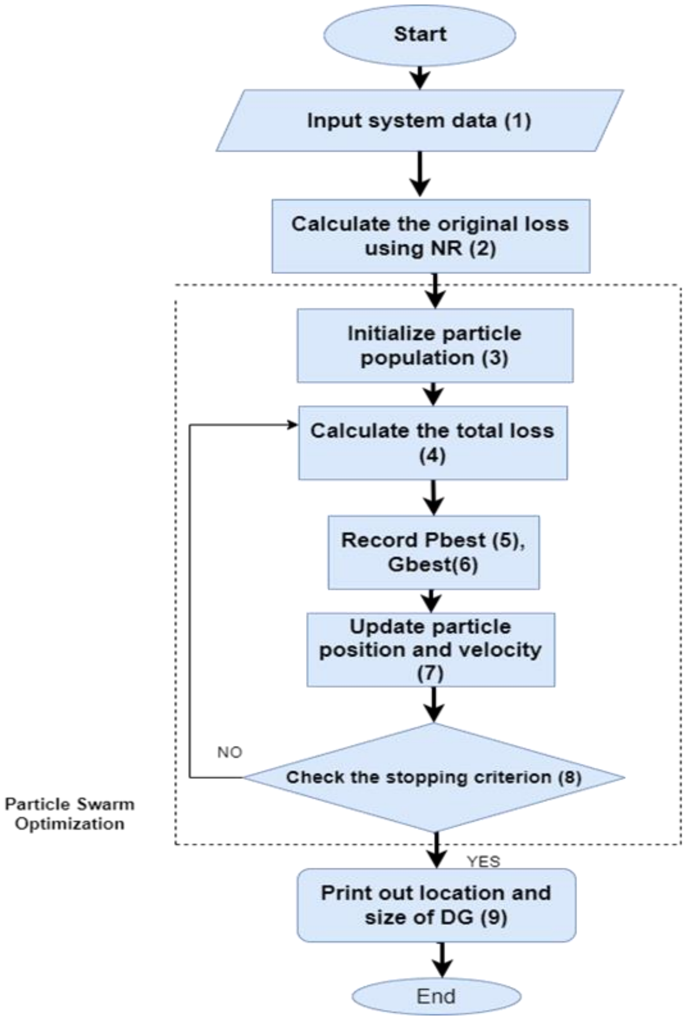

Fig. 3. Flowchart of PSO.

GENERATOR START-UP SEQUENCE

The primary objectives of the black-start generator sequence are twofold. One of these aims is to tackle the substantial increase in energy consumption caused by the proliferation of combined cycle, gas power plant, and distributed generation (DG) facilities in recent years. The second objective is that in the case of a broad power outage, there could be no support from nearby systems. Consequently, the process of restoring the system must begin with a pre-established roster of generating units that possess the potential to initiate their own startup. This list may be used as an initial reference for commencing the restoration procedure, specifically targeting the issue of sequence black beginning. The given R includes the desired unit. The efficiency index of the unit is calculated only by its start-up period. Two crucial aspects that significantly affect the effectiveness of restoration and service recovery are the producing capacity and the overall applicable changeover periods to other units. The main objective of BS is to effectively and securely administer voltage to the target unit throughout the transmission time.

$$\gamma = \frac{1}{D_{BS}} \cdot \left(\frac{P_{bs}}{T_{BS}}\right) \quad , \quad D_{BS} = \sum_{j=1}^{nt} a_j \qquad (4)$$

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$$\delta = \frac{1}{D_{TA}}.\left(\frac{P_{gen}-P_c}{T_{TA}}\right) \quad , \quad D_{TA} = \sum_{i=1}^{nb} b_i \qquad (5)$$

The following equation is used to determine the appropriate BS units:

$$\sum_{i=1}^{N_b} C_i \geq \sum_{J=1}^{N_t} P_c^j \qquad (6)$$

Where: P_{bs}= BS unit's capacity, T_{BS} =BS unit's start-up time,$P_{gen=}$ target unit's max power gen. , T_{TA} = target unit's start-up time , P_C=target unit's consume power, nt=max no. of target, nb= max no. of BS, (a_j, bi)=min. needed switch time, Ci= BS unit's capacity of i^{th} [17] .

THE SELECTION OF TRANSMISSION PATHS

i. Graph commonly represents mathematical models that have insufficient data. Hence, the most efficient resolution to a mathematical problem is comparable to the most efficient resolution of a real-world situation. Hence, it would be advantageous to create supplementary connections between the two specified vertices in order to ascertain the ideal solution based on the incomplete data. The MCSA has been modified and used to locate paths connecting two nodes. If matrix P represents the paths of the base stations in a transmission network with V buses, then P can be described as follows:

$$P=[W_{ij}].V\times V \qquad (7)$$

The weight on the edge, denoted as W_{ij}, is determined by the electrical distance and voltage level. This paper uses the bus bar V as the vertices, the transmission lines E as the edges, and the electrical distance W as the electrical distance k_{ed}. The graph represents the collection of nodes and edges as V_i ∈V, i=1,2,… k_{BB} and e_{ij} ∈ E0V×V i,j=1,2,.. k_{BB}, respectively. The weight0associated with eij E is represented by the element0wij ∈ Wi,j=1,2,.. k_{BB}.The impedance Z (X >> R) x_{ij}=z_{ij} is used to construct the weighted adjacency matrix e_{ij} [18].

ii. PATHS SELECTION CONSTRAIN:

In an overall power system, one may identify several components like as generators, tie lines, transmission lines, transformers, and loads. A complete loss of power occurs in the electrical system, requiring immediate reconfiguration of the network. In order to restore the network, it is important to transport power using a functional channel, as seen in figure 4. In order to establish a feasible path for restoration, it is necessary to consider the limitations of each line and find ways to reduce the cost associated with each line. These limits are described below:

a) When powering the transmission grid under black start circumstances, the quantity of transformers and their nonlinear behavior might result in transient ferro-resonance overvoltage and extended non-harmonic oscillation, both of which can seriously destroy transmission equipment.

b) As the number of switches to be operated rises, the effect of switching surges is catastrophic and the incidence of other transient phenomena would be magnified. Several safeguards have been implemented to mitigate the potential hazards associated with switching surges. The more switching activities there are on the black start route, the longer the black start process will take. The restoration sequence is expressed as follows: $(1,skeleton)$ =$[seq1,seq2,\ldots\ldots seqNsleton]$ (8)

c) The measurement of the network's impedance is used to calculate the electrical distance between the source and destination. Losses would be decreased in proportion to the smallest possible distance between

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ISSN -2708-3985

BS and NBS. by: $electrical\ distance = x \times \boldsymbol{l}\ (km)$ (9)

d) It is necessary for a transmission line's power flow to stay below its capacity. The important restrictions listed above would provide a dependable path for power transmission from the BS generator to the NBS generator.by:

$$|Slineflow| < Sline\ limit. \quad (10)$$

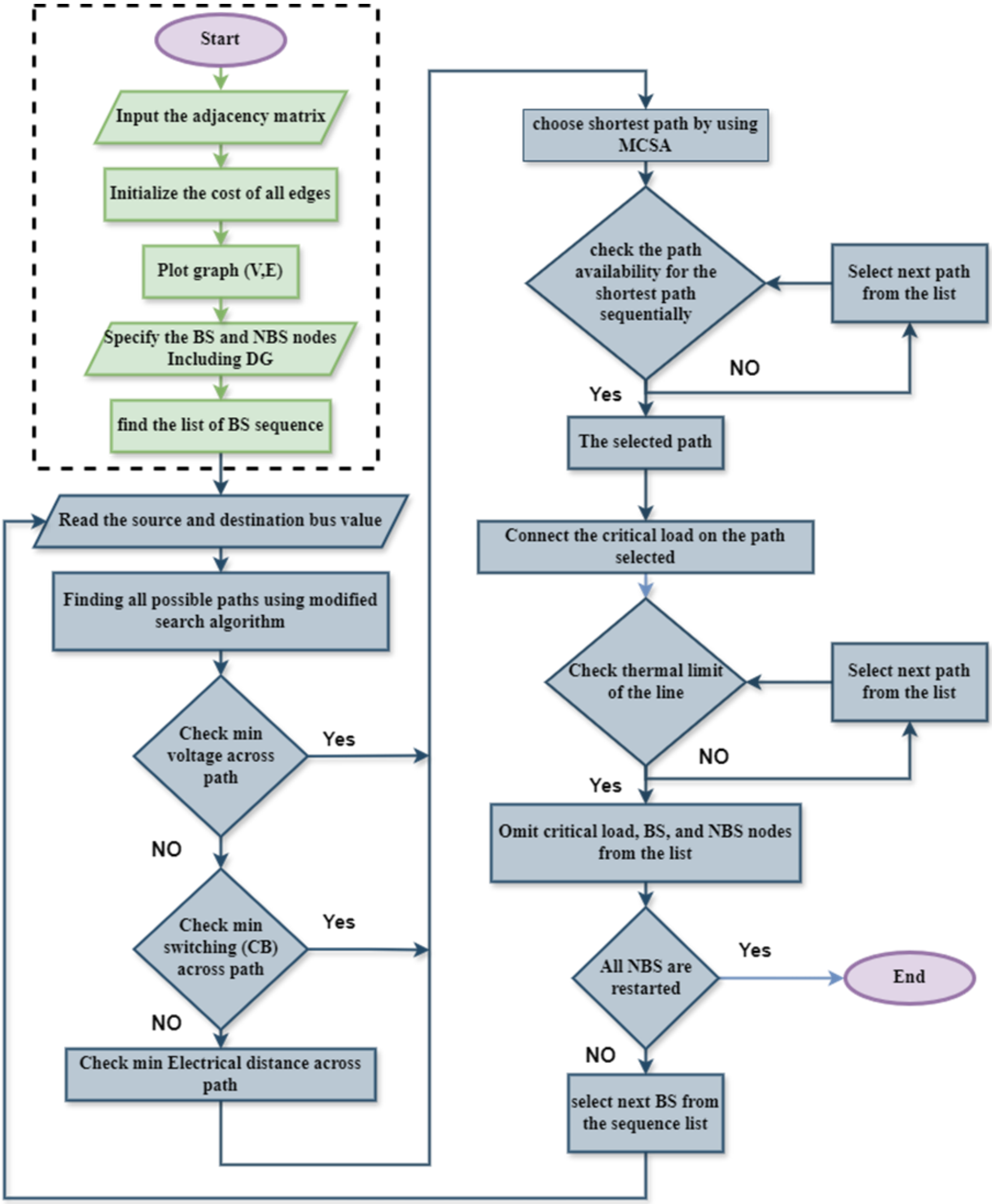

Fig. 4. The computational technique for the selection of generators and the identification of appropriate paths .

Problem Formulation

When a system experiences a fault, it is crucial to restore the system. Achieving time minimization is closely linked to minimizing the quantity of switching operations. The primary aim of this study is to identify the most efficient network for restoration, while minimizing system loss, voltage drop, and the number of switching operations required. The issue has been resolved and examined in two distinct scenarios:

a) Optimized network without Distributed Generation (DG).

b) Optimized network, with DG.

The selection of the DG's position and size is based on the objective of minimizing loss and voltage drop.

OBJECTIVE FUNCTIONS

There are two attractive objectives in multiple functions: increasing the voltage levels for system buses (voltages profile) & minimizing power loss.

objective function (1):minimizing power losses

$$[\text{obj. fun.}(1)] = P_{loss} \tag{11}$$

$$P_{loss} = \sum_{l=1}^{N_{br}} P_{lossl} \tag{12}$$

$$P_{loss} = R_l \times I_l^2 \tag{13}$$

Where :

P_{loss}: overall losses , N_{br}: the number of network branches , R_l : branch resistance , I_l^2: current for branch.

objective function (2): Voltage Profile

$$[\text{obj. fun.}(2)] = V_c \times Re_v + C_c \times Re_i \tag{14}$$

V_c: bus's voltage limits, C_c: limitations on branch's currents,Re_v: variable the retaliation of the bus's voltage,

[obj. fun.(1)+ obj. fun.(2)=Objective function final] (15)

TWO STEP ALGORITHM FOR GENERATION CAPABILITY CURVE

The amount of power (MW) capability of each BS or NBS generator P_{igen} can be expressed by area between its generation (minuses the startup requirement). Capability curve and the time horizon are shown in Fig.(5) [19].

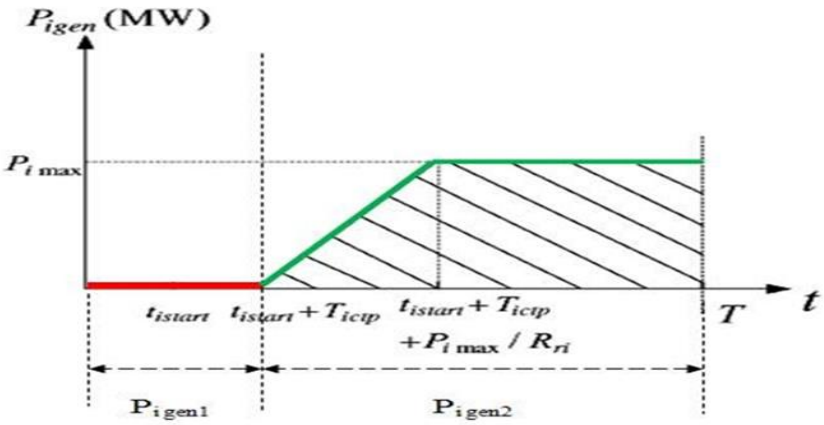

Fig. 5. Power capability curve.

Where P_{max}: is the maximum generator active power output, t_{start} is generator starting time T_{ctp} is cranking time for generators to ramp and parallel with the system, R_r is the generator ramping rate, and T is the total restoration time. It is assumed that all BS generators are stored at the beginning of restoration. Critical time constrains: generators with constrains of T_{cmax} or T_{cmin} should satisfy the following:

$$t_{istart} \geq T_{icmin}, \forall i \in set\ of\ gen$$
$$t_{istart} \leq T_{icmax} \quad (16)$$

T_{cmin} is minimum critical time (cold start), and , T_{cmax} Maximum critical time (hot start).

The startup power requirement:

$$\sum P_{igen(t)} - \sum_{j=1}^{m} P_{jstart} \geq 0 \quad t = 1,2, \ldots T \quad (17)$$

Where, $P_{igen(t)}$ is the generation capability function if unit i, P_{jstart} is the startup power function of NBS unit j. t_{jstart} : where NBS generator reject the cranking power to startup. t_{ictp} : time generator start to ramp up. During of generator to reach the maximum capacity it can be found as in eq.(18):

$$(t_{istart}, 0), to \mid t_{istart} + \frac{P_{max}}{R_r}), P_{max} \quad (18)$$

For each generator, the generation capability curve is divided in to two segments as show in fig.(5)[19] . Furthermore, One segment P_{igen1} is from original to the corner point where the generator begins to ramp up. While, the other segment P_{igen2} is from the corner point to point when all generators

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have been started, the quasi concave function is converted into two concave functions.

The generator capability function P_{igen} can be expressed as:

$$P_{igen} = P_{igen(t)} + P_{igenz(t)} \tag{19}$$

$$P_{igen(t)m} = 0 \qquad 0 \le t \le t_{istart} \tag{20}$$

$$P_{gen2(t)} = R_r\,(t - t_{start}) \tag{21}$$

$$P_{isen2(t)} \le P_{imax}$$

SIMULATION RESULT

The proposed method for restoration is tested by employing the IEEE 39-bus system simulates a power grid following a significant power failure, as seen in figure (6). Cuckoo search algorithm is tested in IEEE 39 bus system for to find the shortest path with Pickup load sequence. Cuckoo search algorithm Island 1 after sectionalizes the system. Possible combination each NBS unit and all other nodes. Depends upon the combination it select the shortest path node to Pick-up the load with all the constraints is satisfied. In the IEEE 39 Bus system considers are 7 NBS unit generators, 3 BS generators and 29 Load. Each NBS generators are frontrunner for some loads. The scenario involves the utilization of a MCSA technique. The conditions were set as checking the minimum number of switching then minimum electrical distance. PSO based method for resolving a multi-objective service hot and cold start restoration issue both without and with distributed generation.

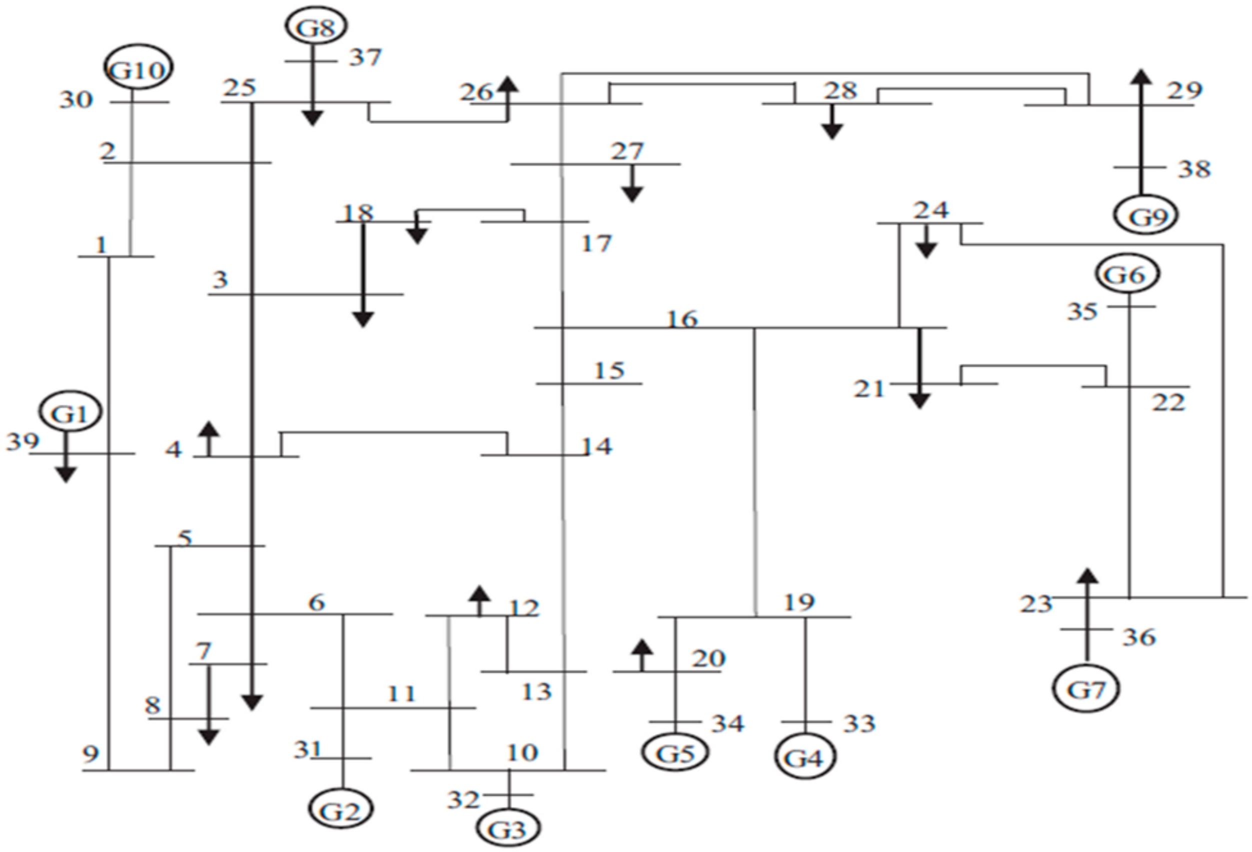

Fig. 6. One line diagram of England IEEE 39-bus.

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The topology structure of England IEEE 39-bus system is given in Fig. (7) which is generated by means of graph theory using undirected weighted graph representation. Each bus was represented by a node and transmission line represented by a weighted edge.

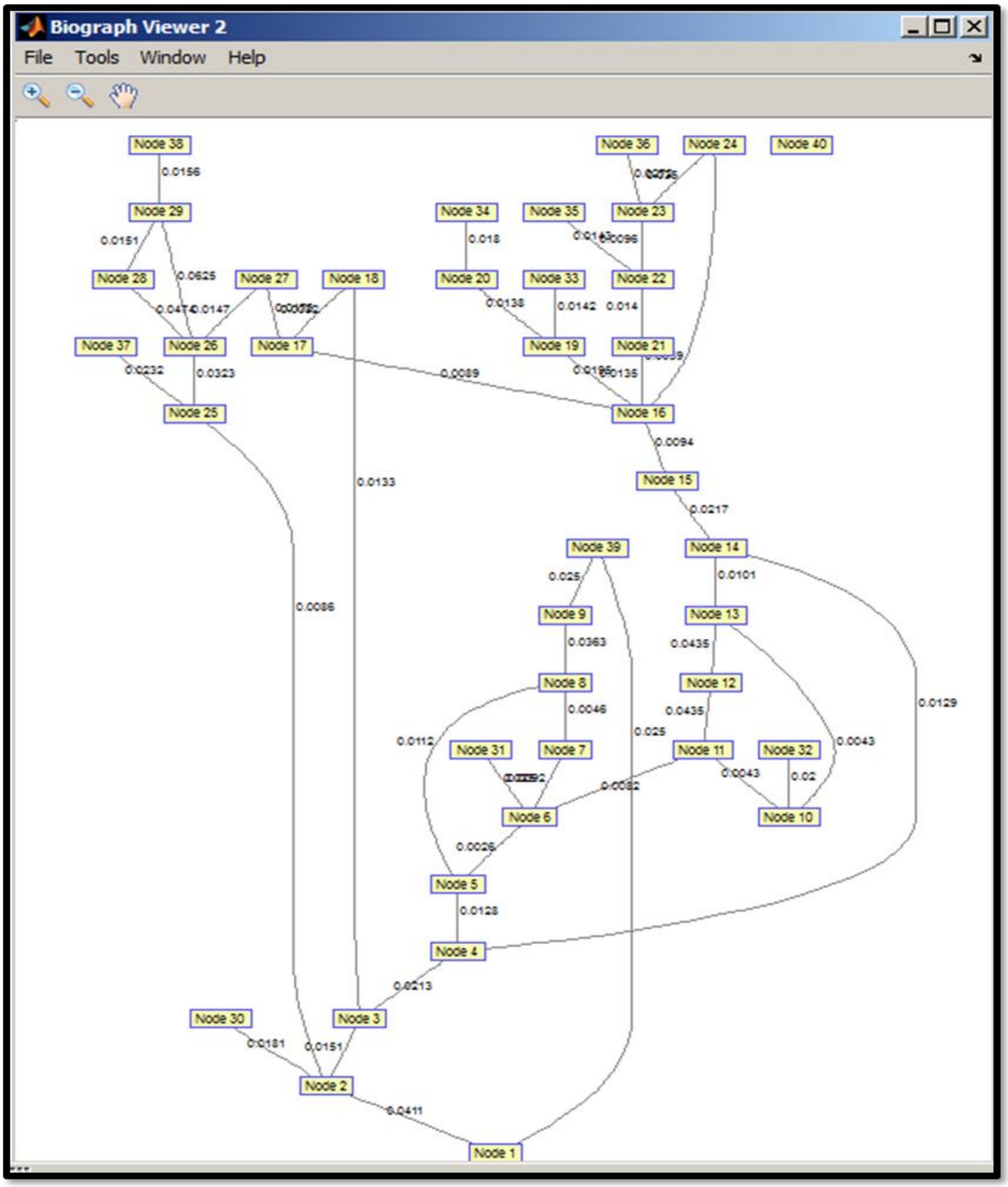

Fig. 7. The topology structure of England IEEE 39-bus system by mean of graph theory.

There are three stages for simulated outcomes; for the power system restoration procedure, a crucial step is to initiate load pick-up and beginning the non-black-start unit using the black-start unit with distributed generation. In order to decrease restoration time and difficulty, the system must discover the shortest path between two nodes; MCSA is used to determine the optimal pathways for restoring power in a grid show as table (1&2).

a) First-stage: The three islands are referred to as Island 1, Island 2, and Island 3 in Stage 1. Island 1's G1 units, L1, L2, and L3, satisfy load demand. The G8 units, L4, L5, and L6, satisfy load demand. And G9 get together L7 and L8 are the load demands.L9 and L10 are the load demands that Island 2 NBS unit G6 can meet. NBS unit G4 satisfies L12 and L11 load demands. L14 and L15 in Island 3 NBS unit G3 meet load demand .The G1, G6, and G3 NBS units are powered to load for the purposes of Stage 1 testing. The IEEE 39 bus systems' shortest route between two nodes . On Island 1, B39 is the shortest path from G1 to L1, B39-B1-B2-B3, and B39-B1-B2-B3-B18 is the shortest path from G1 to L3. The shortest paths on Island 2 are G6 to L9 (B21) and G6 to L10 (B35-B22-B23). The shortest paths on Island 3 are G3 to L14 (B32-B10-B13) and G3 to L15 (B32-B10-B13-B14-B15).

b) Second-stage: The power to load is provided to G8, G4, and G2 NBS units for Stage 2 testing purposes. The shortest path in the IEEE 39 bus system between two nodes . The shortest path from G8 to L4 in Island 1 is B37-B25. The shortest path from G8 to L5 is B37-B25-B26. The shortest path from G8 to L6 is B37-B25-B26-B27. The shortest path from G4 to L12 in Island 2 is B33-B19-B16. The shortest path from G6 to L10 is B33-B19-B16-B24. The shortest path from G2 to L16 in Island3 is B31. The shortest path from G2 to L18 is B31-B6-B7. The shortest path from G2 to L19 is B31-B6-B7-B8. The shortest path from G2 to L17 is B31-B6-B5-B4.

c) Third-stage: During Stage 3 testing, the G9, G4, and G2 NBS units are responsible for supplying power to the load and activating each generator. The shortest path between two nodes in the IEEE 39 bus system . The shortest path from G9 to L7 in Island 1 is B38-. The shortest path from G9 to L8 is B38-B39-B28. The shortest path from G4 to L12 in Island 2 is B33-B19-B16. Similarly, the shortest path from G6 to L10 is B33-B19-B16-B24. In Island3, the shortest path from G2 to L16 is B31. The shortest path from G2 to L18 is B31-B6-B7. The shortest path from G2 to L19 is B31-B6-B7-B8. The shortest path from G2 to L17 is B31-B6-B5-B4.

Table 1. Feasible paths from BS to NBS.

BS	NBS	Shortest path	Number of switching	Electrical Distance
G-BS5	G2	B34-B20-B19-B16-B15-B14-B4-B5-B6-B31	10	0.0742
		B34-B20-B19-B16-B15-B14-B13-B12-B11-B6-B31	11	0.09398
	G3	B34-B20-B19-B16-B15-B14-B13-B12-B11-B10-B32	11	0.077453
		B34-B20-B19-B16-B15-B14-B4-B5-B6-B11-B10-B32	12	0.09630
G-BS7	G4	B36-B23-B19-B33	4	0.0979
	G6	B36-B23-B22-B35	4	0.0999
G-BS10	G1	B30-B2-B1-B39	4	0.1759
		B30-B2-B3-B4-B5-B8-B9-B39	8	0.1797
	G8	B30-B2-B25-B37	4	0.17001
	G9	B30-B2-B25-B20-B28-B29-B38	7	0.18076
		B30-B2-B3-B18-B17-B27-B28-B29-B38	9	0.1076

Table 2. NBS unit to Load restoration shortest transmission path

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S.NO	NBS unit	Load	**Shortest transmission path**	Weight index	Priority order
1	G1	L1	B39	1	1
		L2	B39-B1-B2-B3	4	2
		L3	B39-B1-B2-B3-B18	5	3
2	G8	L4	B37-B25	2	1
		L5	B37-B25-B26	3	2
		L6	B37-B25-B26-B27	4	3
3	G9	L7	B38-B29	2	1
		L8	B38-B29-B28	3	2
4	G6	L9	B35-B22-B21	3	1
		L10	B35-B22-B23	3	2
5	G4	L12	B33-B19-B16	3	1
		L11	B33-B19-B16-B24	4	2
6	G3	L14	B32-B10-B13	3	1
		L15	B32-B10-B13-B14-B15	5	2
7	G2	L16	B31	1	1
		L17	B31-B6-B5-B4	4	2
		L18	B31-B6-B7	3	3
		L19	B31-B6-B7-B8	4	4

The data of generators through power capability curve for IEEE 39- bus for hot and cold start generators in table (A1) of Appendix A.

Restoration network, with DG and without Distributed Generation (DG) for this process the power capability curve were drawn for hot start generator and cold start generators. Adding distributed generation using the PSO algorithm. DG selection (location and size) in three cases shown in table (3).

Table 3. Selected size and location by using particle swarm optimization .

NO. of DG	**DG Location**	**DG Size in (MW)**	**Total losses without DG MW**	**Total losses with DG MW**	**Total losses reduction in MW**	**Bus voltage in p.u**
DG1	31	6.900	45.956	45.025	0.931	0.95<V<1.06
DG2	32	8.553				
DG3	33	7.766				

Adding distributed generation (DG) at an appropriate size and location significantly decreases system loss as well as voltage drop to greater levels are given in fig.(8) and fig.(9).

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ISSN -2708-3985

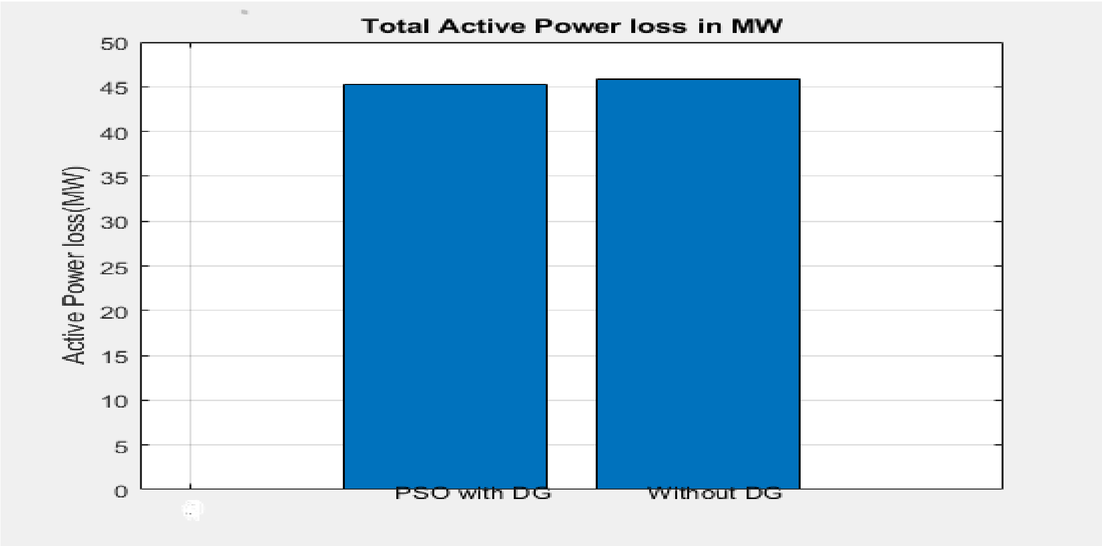

Fig. 8. Active power losses (with & without DG) using PSO algorithm

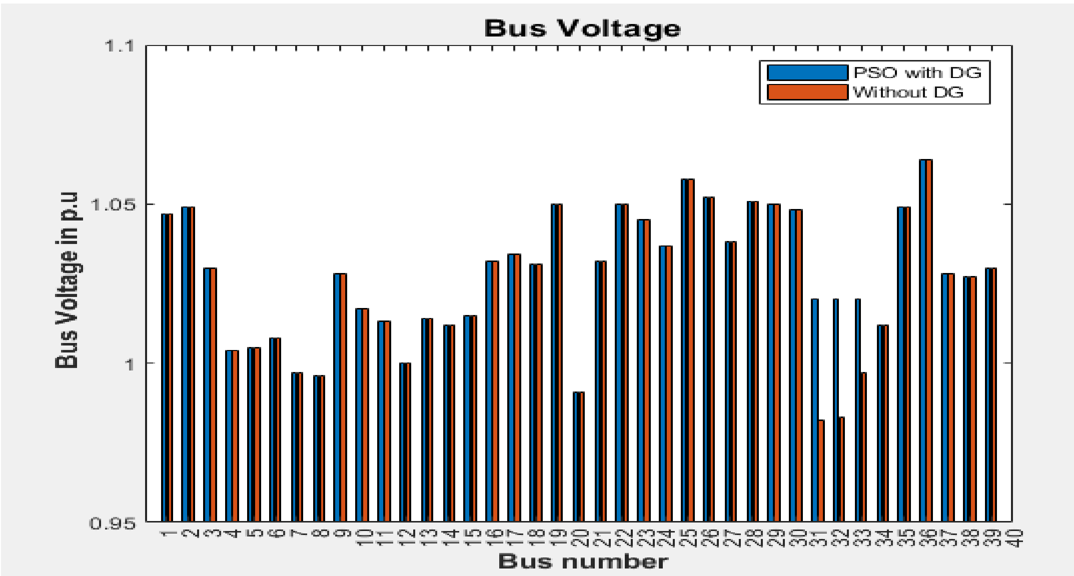

Fig. 9. Voltage Profile without and with DG using (PSO).

To restore grid IEEE 39 bus the distributed generation (DG) contributes to improving grid recovery in a faster time than the traditional method (without DG). This is a graphical representation of the maximum active and reactive power outputs of generators of ieee39-bus system red Line (Upper Before Addition): This represents the maximum active and reactive power outputs of the generators before the addition of distributed generation (DG). Blue Line (Impact of Distributed Generation): This represents the system's performance after distributed generation has been added. The graph showing improvements in power restoration or overall system performance due to the addition of DG. It is influenced by generator limits, system voltage, and thermal limits of transmission line are given in fig. (10) and fig. (11).

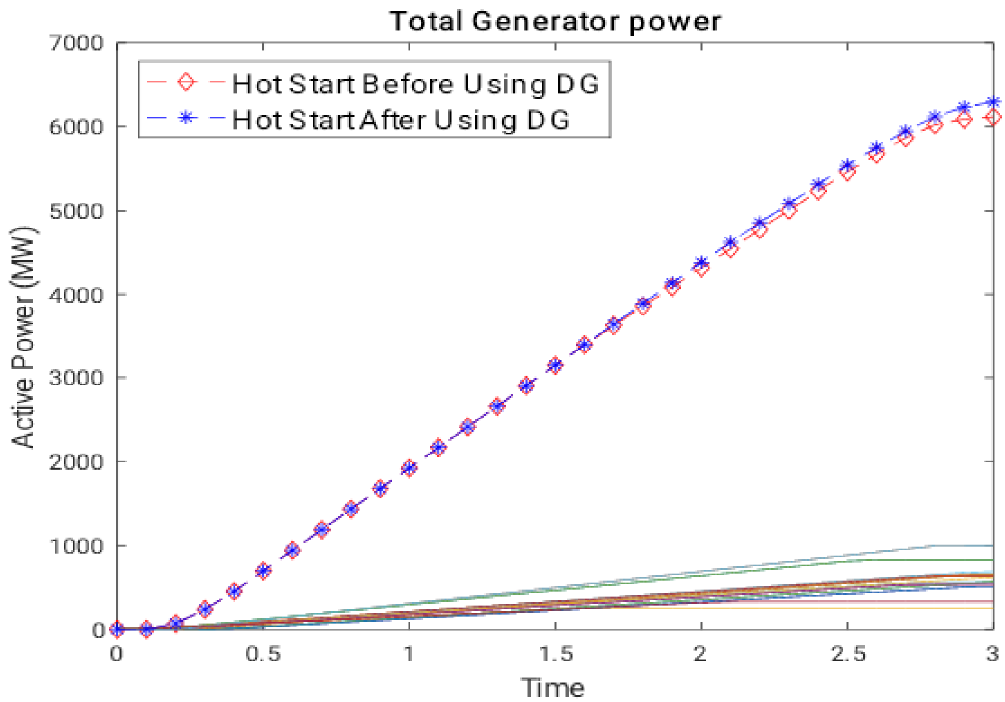

Fig. 10. Power capability curve for IEEE 39 bus for hot start generators with &without DG.

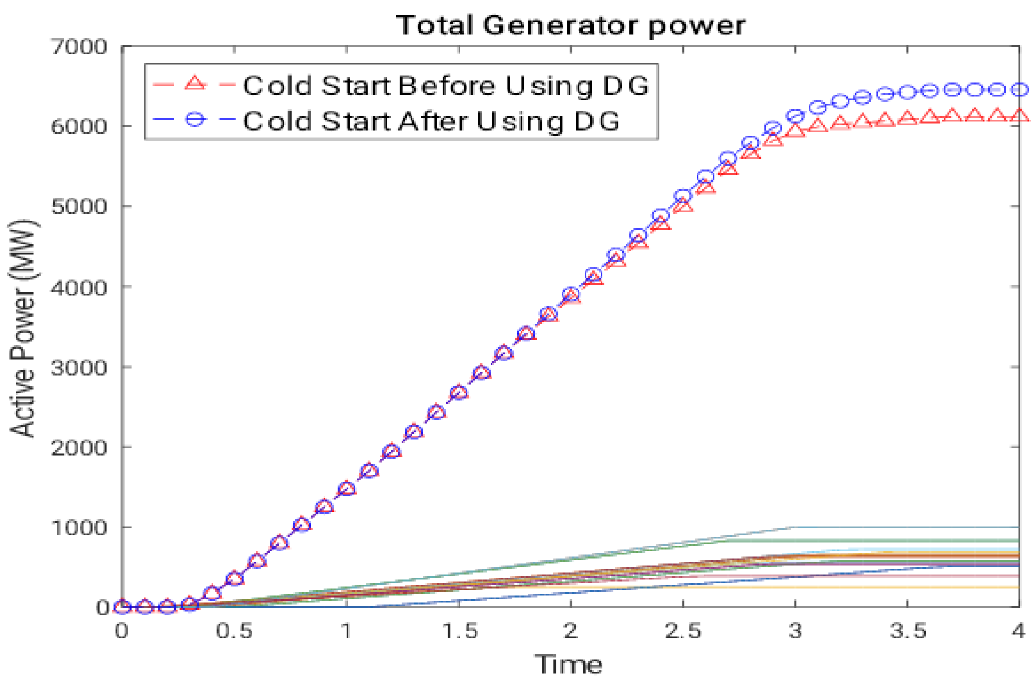

Fig. 21. Power capability curve for IEEE 39 bus for cold start generators with &without DG.

The analysis of power capability curves for the IEEE 39-bus system clearly demonstrates the benefits of incorporating DG with both hot and cold start generators. DG units play a critical role in enhancing power output, improving voltage stability, and significantly reducing grid recovery time. These findings underscore the importance of integrating distributed generation into power systems to bolster resilience and efficiency during recovery operations.

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CONCLUSION

The determination of the restoration sequence for a power system after blackout is a multifaceted challenge that involves multiple objectives, stages, and constraints. This work presents a novel expert technique for power system operators to achieve a rapid and secure restoration procedure. The procedure involves the utilization of a Modified Cuckoo Search algorithm. MSCA is used to facilitate the restoration process by establishing arranges to a generator sequence with viable routes from the black start to the non-black start and load pick-up. An analysis is conducted by a Particle Swarm Optimization method for resolving a multi-objective service restoration issue both without and with distributed generation. Adding distributed generation (DG) at an appropriate size and location significantly decreases system loss as well as voltage drop to greater levels. As a result, in the event of a blackout, restore time will be minimum and system restoration will be secure and efficient. Any network may be assured to converge according to the "Newton Raphson" load flow method. The proposed approach may be evaluated on an actual system to assess its efficacy in actual-world scenarios.

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Appendix A: IEEE-39 Bus Test Systems

Table (A1): Data of generators characteristics.

Number Gen.	Node Number	T ctp (hr)	Tcmin (hr)	Tcmax (hr)	Ri (MW/hr)	Pstart (MW)	Pmax (MW)
G1	39	0:35	0.35	0.50	384	15	1000
G2	31	0:35	0.15	0.30	215	5.5	572.9
G3	32	0:35	0.10	0.20	246	8	650
G4	33	0:35	0.35	1.10	236	7	632
G5	34	0:35	0.25	0.40	198	5	508
G6	35	0:35	0.10	0.20	244	8	650
G7	36	0:35	0.15	0.30	214	6	560
G8	37	0:35	0.15	0.30	210	6	540
G9	38	0:35	0.2	0.40	346	13.2	830
G10	30	0:15	0.05	0.15	162	0	250

Where :

Ri: Ramping rate of generator,
Pmax : Maximum power of generator,
Pstart : Power starting time of Generator ,
Tcpt : Cranking time for generator
Tcmin: Minimum critical time (hot start)
Tcmax: Maximum critical time (cold start)