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Techno-Economic and Environmental Benefit Analysis of PV and D-FACTS-Enriched Modern Electric Distribution Grid with Practical Loads

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Abstract: In the current era, expansion in the power system has led to an increase in the Distributed Generation (DG) planning to accomplish the increase in demand. Hence because of the opted DG's inappropriate planning, the system gets unbalanced with an increase in losses, voltage profile imbalance along with reliability issues. Here, the modernized IEEE 69-bus network is considered for appropriate DG's planning. In this study, one important factor, which is the Line Fault Current Level (LFC^{Level}) along with Real & Reactive Losses (R^{Loss} & Q^{Loss}), Voltage Deviation Profile (V^{DP}), and Network Reliability (R^{N}), is considered as an index in the objective function, which makes the proposed Multi-Objective Function (MOF) a novel MOF (nMOF). The cost-economic and Pollutant Gas Emissions (PGE) parameters are also examined in accordance with this nMOF optimized outcomes. In the proposed study, the DG's (PV and D-FACTS) are planned optimally with reconfiguration incorporating practical loads (industrial, commercial, and residential) using an Adaptive Particle-Swarm Optimization (APSO) approach through coding in MATLAB software. Then the techno-economic and environmental-benefit analysis of the outcomes reveals that the R^{Loss}, Q^{Loss}, cost, and PGE are reduced by 96.58 %, 94.39 %, 78.02 %, and 92.58 % with an improved balanced profile of voltage, LFC^{Level}, and R^{N}.

Keywords: Photo-Voltaic (PV), Distributed-Flexible AC Transmission System (D-FACTS), Tie-Switches (TS), novel Multi-Objective-Function (nMOF), Pollutant Gas Emissions (PGE), Adaptive Particle Swarm Optimization (APSO).

1. INTRODUCTION

In the trending era, the electricity supply must be enriched with quality and reliability, then the power industry can deal with the rising demand for electricity. The optimal application of Distributed Generations (DG) in the power industry can provide an enriched electricity supply to the end users with improved quality and reliability. That is why in the proposed study, the techno-economic and environmental (TEE) benefit analysis of Photo-Voltaic (PV) and Distributed-Flexible AC Transmission System (D-FACTS) enriched modern distribution grid for real and reactive power support with practical load is carried out. The relevant findings in different literature for DG planning in reconfigured and unconfigured Distribution Systems (DS) are discussed below.

In [1], the author has proposed a planning approach of renewable DG and Distribution STATic COMpensator (DSTATCOM) in the IEEE 69 bus test system using DRTO (Discrete Rooted Tree Optimization) to improve the different techno-economic parameters. In literature [2], the DG planning is carried out in IEEE 33, 69 and practically loaded 54-bus test system to improve the system performance. Implementation of DGs in a 33 and 69-bus DS using hybrid Particle-Swarm Optimization and Dragonfly-Algorithm (hybrid PSO-DA optimization) has been taking place with DS reconfiguration, the result reveals benefit in DG installation-maintenance cost with a reduction in loss [3]. Through network reconfiguration and DG integration, [4] seeks to improve the IEEE 33 and 69-bus DS planning to diminish loss by raising the DS result's excellence under consideration by optimizing via Water-Cycle Algorithm (WCA). The work discussed in reference [5] focuses on maintaining the synchronization of protective devices following voltage planning, aiming to minimize losses and deviations in voltage. This objective is achieved by utilizing Firefly and Evolutionary Algorithms (FA and EA) within three IEEE DS, such as 33, 69, and 118-bus. The contents of reference [6] encompass examining the annual energy loss reduction through mitigating voltage deviation and real power loss. This endeavor is pursued utilizing Teaching-Learning-based Optimization (TLBO) and Intellect hunt-based TLBO (ITLBO) methodologies, implemented via DS reconfiguration and DG installation. The study encompasses two test systems, specifically the 33 & 69 along with a practical 83-bus DS. Applied Load

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Flow Method (LFM), i.e., the Backward-Forward Sweep LFM (BFSLFM) for the proposed study, is given in [7], [8], [9]. In [10], the author has presented a strategy for planning DGs alongside control and protective devices, employing the Non-Dominated-Sorting Genetic-Algorithm II (NSGA II). The author presents a microgrid formulation strategy for the three-phase IEEE 34 and 123 bus network to mitigate the sudden severe outage [11]. In the literature [12], [13], [14], [15], different optimization techniques are used for various kinds of distribution network planning to enhance the system objectives. Optimization techniques called PSO and Adaptive PSO (APSO) are mentioned in [16], [17]. The reference [18] introduces an analysis of a DS, considering the influence of Factor for Emission (E_F). The optimal DG siting-sizing has been carried out using an Improved Decomposition-Based Evolutionary Algorithm (IDBEA) [19], Artificial Humming-bird Algorithm (AHA) [20], and Point Estimate Method (PEM) [21], respectively.

The comprehensive review of existing literature highlights various significant techno-economic and environmental challenges within the DS. These challenges encompass issues like R^{Loss}, Q^{Loss}, V^{DP}, inadequate R^N, and the limited fault current tolerance capacity of the lines leading to elevated LFCLevel accompanied by substantial PGE and cost. Consequently, the DS service quality and reliability suffer. To enhance these aspects, minimizing the parameters such as R^{Loss}, Q^{Loss}, V^{DP}, PGE, and cost is imperative while simultaneously improving R^N and LFC^{Level}. Strikingly, none of the previous works in the literature have simultaneously addressed all these technical concerns as objectives for enhancing DS service quality, reliability, and cost-effectiveness. Hence, this is the driving force for the proposed work, wherein all these issues collectively form a nMOF. The primary motivation is to address these challenges holistically. As a result, the proposed work involves the integration of multiple PV and D-FACTS elements into a modernized and reconfigured 69-bus DS. This integration is optimized using the APSO method, taking the nMOF as the basis for the analysis. The ultimate aim is to achieve improvements in techno-economic and environmental benefits.

Consequently, for the analysis, a trio of case studies has been introduced: (i) Basic System Study (BS), illustrating the unmodified system scenario; (ii) Proposed Study-1 (PS-1), centered on the optimal integration of multiple PV and D-FACTS components into a modernized 69-bus network; and (iii) Proposed Study-2 (PS-2), focusing on the optimal integration of multiple PV and D-FACTS components into a modernized and reconfigured 69-bus network. The proposed research is structured into five distinct sections: Introduction, Modeling, Methodology Presentation, Results Analysis, and Conclusion, respectively.

In this paper, the following novel and significant contributions are reported:

1) Introduces an nMOF, addressing five pivotal technical challenges: R^{Loss}, Q^{Loss}, V^{DP}, compromised R^N, and elevated LFC^{Level} indicating deficient fault current acceptance ability of the branches/lines.
2) Within the nMOF, an index is incorporated to quantify the enhancement of fault current acceptance, defined as LFC^{Level}.
3) The analysis considers the economic perspective of DS, incorporating various costs: cost for Fixed Capital-Recovery (C^{FIX}), Energy-Loss (C^{LOSS}), and Average-Energy Not-provided/Supplied (C^{AENS}).
4) The environmental performance parameters are also addressed, including the impact of Pollutant Gas Emissions (PGE) like Nitrogen Oxide (NO_X), Sulfur-Dioxide (SO_2), and Carbon Dioxide (CO_2).
5) The standard IEEE 69-bus test network is modernized as a modernized 69-bus network. Based on each bus loading capacity, the practical loads (industrial, commercial and residential) are incorporated into the respective buses.
6) Utilizing the APSO, the nMOF is optimized for the optimal integration of multiple PV and D-FACTS technologies within a modernized and reconfigured 69-bus network, enhancing techno-economic and environmental benefits.
7) A comparative analysis of BS, PS-1, and PS-2 utilizing APSO is presented to validate the effectiveness of the proposed approach from the considered perspectives for the modernized 69-bus network. Furthermore, the results are compared with recent publications in the field.

2. MODELLING: LOAD, PV, AND D-FACTS

A. Load Modelling

The loads in the distribution system are different over the day; that is, loads are not always constant. Therefore, to develop a modern/practical electric distribution grid, it is very important to consider practical loads like industrial and commercial with residential loads. That is why for the proposed study, practical exponential mixed loads are considered in the basic 69-bus IEEE test network for its modernization based on the voltage dependency of active and reactive power [2]. The practical loading (i.e., practical load allocation) at the buses of the basic IEEE 69-bus test network has been done by considering the modern loads in place of the traditional constant load of the basic system, as presented in Table I.

$$P_D^i = P_D^o \left(\frac{V^i}{V^o} \right)^{\alpha} \quad (1)$$

$$Q_D^i = Q_D^o \left(\frac{V^i}{V^o} \right)^{\beta} \quad (2)$$

Where, P_D^i & Q_D^i denoted real-power & reactive-power demand of the load at the i^{th} bus with voltage V^i, P_D^o & Q_D^o are the operating points real-power & reactive-power demand of the load at the i^{th} bus with voltage V^o, and the

α, β as exponent values for real, reactive power loads as given in Table II.

TABLE I. DIFFERENT LOAD MODELS AT THE BUSES OF MODERNIZED IEEE 69-BUS TEST NETWORK

Type of Loads	Buses
Industrial	11, 12, 21, 49, 50, 59, 61, 64
Residential	7, 8, 9, 16,17, 18, 28, 29, 45, 46, 48, 51, 62, 65, 68, 69
Commercial	6, 10, 13, 14, 20, 22, 24, 26, 27, 33, 34, 35, 36, 37, 39, 40, 41, 43, 52, 53, 54, 55, 66, 67

TABLE II. PRACTICAL LOADS WITH THEIR EXPONENT DETAILS

Type of Loads	α	β
Constant-Load	0.0000	0.0000
Industrial-Load	0.1800	6.0000
Residential-Load	0.9200	4.0400
Commercial-Load	1.5100	3.4000

B. PV Modelling

Power generation from photovoltaic (PV) sources presents a solution to reduce reliance on fossil fuels within the power sector [1], [14]. The formulas used to determine power output and efficiency are presented as Eq. (3) and Eq. (4).

$$P_{PV} = aH\eta^{PV} \tag{3}$$

$$\eta^{PV} = \eta^{STC}\left[1 + \zeta\left(T^{cell} - 25\right)\right] \tag{4}$$

Where P_{PV}=PV power, a= panel area in (m^2), and H=solar-radiation W/m^2. Efficiency can be evaluated through η^{PV} and η^{STC} within predefined operational conditions in standardized test states (STC). The cell temperature T^{cell} in C, and ζ =C.

C. D-FACTS Modelling

In this study, the DSTATCOM functions as a reactive power DG ($Q_{D-FACTS}$) i.e., D-FACTS device. Eq. (5) and (6) present an estimated equation for correcting angle and voltage through D-FACTS current injection [14]. Once D-FACTS is installed at the $(y+1)^{th}$ bus, both current I_k and $I_{D-FACTS}$ traverse the path concurrently. The injection of $Q_{D-FACTS}$ for voltage correction at the $(y+1)^{th}$ bus is depicted in Eq (7):

$$\angle I_{D-FACTS} = \frac{\pi}{2} + \mu'_{y+1} \tag{5}$$

$$\begin{aligned} V'_{y+1}\angle\theta'_{y+1} = {} & V'_y\angle\theta'_y - \left(R_y + jX_y\right) \\ & \times\left\{I_y\angle\delta + I_{D-FACTS}\angle\left(\tfrac{\pi}{2} + \mu'_{y+1}\right)\right\} \end{aligned} \tag{6}$$

$$Q^{Injection}_{D-FACTS} = \left(V'_{y+1}\angle\theta'_{y+1}\right)\left\{I_{D-FACTS}\angle\left(\frac{\pi}{2} + \mu'_{y+1}\right)\right\}^* \tag{7}$$

The injected current via D-FACTS ($I_{D-FACTS}$) and the alteration in angle (μ'_{y+1}) will both diminish to zero if the voltage remains consistent before and after D-FACTS installation at $(y+1)^{th}$ bus, which occurs at $V'_{(y+1)}$ equals $V_{(y+1)}$.

3. PRESENTED METHODOLOGY

A. Modelling of nMOF, Cost and PGE Parameter

In this part, a nMOF is proposed in which one important factor, i.e., LFC^{Level} along with R^{Loss}, Q^{Loss}, V^{DP}, and R^N, is considered as an index in the objective function, which makes the proposed multi-objective-function a novel Multi-Objective-Function (nMOF). By using this nMOF, the techno-economic and environmental-benefit analysis of PV and D-FACTS enriched reconfigured distribution system for real and reactive power support with practical load models is carried out. The nMOF is mathematically represented as:

$$\begin{aligned} nMOF = {} & \varepsilon_1 \times IR^{Loss} + \varepsilon_2 \times IV^{DP} + \varepsilon_3 \times IQ^{Loss} \\ & + \varepsilon_4 \times ILFC^{Level} + \varepsilon_5 \times IR^N \end{aligned} \tag{8}$$

Where the weight-factors ε_1, ε_2, ε_3, ε_4, and ε_5 are represented by the weight values 0.30, 0.25, 0.20, 0.15, and 0.10, respectively. The literature [2] provides a detailed explanation of the notion of choosing the weight elements. These variables express the exact weights assigned to each system variable index. When planning DGs with reconfiguration, their values are chosen depending on the importance of each specific index's performance.

1) Calculations of nMOF indices are as follows using the below formulae: -
   - Loss of real power index,

$$IR^{Loss}_{\delta} = \frac{R^{Loss}_{\delta}}{R^{Loss}_{BS}} \tag{9}$$

   - Loss of reactive power index,

$$IQ^{Loss}_{\delta} = \frac{Q^{Loss}_{\delta}}{Q^{Loss}_{BS}} \tag{10}$$

   - Deviation in voltage profile index,

$$IV^{DP}_{\delta} = \max\left(\frac{\Delta V^{\delta}}{v_{ref}}\right) \tag{11}$$

   - The LFC^{Level} index,

$$ILFC^{Level}_{\delta} = \frac{LFC^{Level}_{\delta}}{LFC^{Level}_{BS}} \tag{12}$$

   - Determination of R^N index,

$$\mathrm{IR}^{\mathrm{N}}_{\delta} = \frac{\text{Total MVA Intrupted}^{\delta}}{\text{Total MVA Intrupted}^{\mathrm{BS}}} \tag{13}$$

   where δ is the proposed study 1 and 2.
2) The following are the system cost parameters for calculating the various costs: C^{FIX}, C^{LOSS}, and C^{AENS} [2]:-
   - System fixed cost of capital recovery (C^{FIX}),

$$C^{FIX} = h\sum_{BRN=1}^{N_{BRN}} C_{BRN} \tag{14}$$

- Cost of average energy not supplied (C^{AENS}),

$$C^{AENS} = C_i \times AENS \tag{15}$$

- The cost of energy losses (C^{LOSS}),

$$C^{LOSS} = 8760 \times C_l \times f \times \sum_{BRN=1}^{N_{BRN}} I_{BRN}^2 \times R_{BRN} \tag{16}$$

$$\phi = 0.15 \times \varphi + 0.85 \times \varphi^2 \tag{17}$$

The variables N_{BRN}, I_{BRN}, R_{BRN}, and C_{BRN} denote the main feeder's branch number, current, resistance, and cost. The h, ϕ, φ, C_i, and C_l are the yearly-recovery rate of the fixed cost, factor for load, factor for loss, per unit cost of AENS, and energy loss.

3) Calculation of Pollutant Gas Emission (PGE) parameters:-
The environmental performance parameters encompass CO_2, SO_2, and NO_X as integral components of the PGE assessment. It is presumed that the utility providing power to consumers relies on conventional thermal power generation methods, thereby implicating PGE. These factors significantly impact both the environment and human well-being adversely. Specifically, CO_2, SO_2, and NO_X each exhibit E_F of 632, 2.74, and 1.34 grams per kWh, correspondingly [18].

$$PGE^{BS\ or\ \delta} = PE_F \times P_{GRID}^{BS\ or\ \delta} \tag{18}$$

B. Optimization Approach

The PSO was announced in 1995 [16], followed by the APSO developed in 2009 [17]. The APSO is a population-based iterative approach that involves the continuous updating of swarm velocity and position. By initializing system parameters as a swarm and iteratively adjusting swarm velocities and positions until convergence, the optimal solution for the MOF can be attained. The variables V^k and S^k denote velocities and positions from the preceding generation. To update these values for the $(k+1)^{th}$ generation, fundamental equations for velocity and position adjustments are provided as Eq. (19) and Eq. (20).

$$V^{x+1} = \rho \times [w^x \times V^x + c^1 \times r^1 \times \left(S^{personalbest} - S\right) + c^2 \times r^2 \times \left(\left(S^{globalbest}\right) - S\right)] \tag{19}$$

$$S^{x+1} = S^x + V^x \tag{20}$$

$$w^k = w^{\max} - (w^{\max} - w^{\min})\frac{Ir^k}{Ir^{\max}} \tag{21}$$

$$\rho = \frac{2}{\left|2 - \psi - \sqrt{\psi^2 - 4\psi}\right|} \tag{22}$$

$$\psi = c_1 + c_2 = 4.1 \tag{23}$$

Where, V denotes the velocity of each individual swarm. The velocity, swarm-population are represented as V^{x+1}, S^{x+1} for the $(k+1)^{th}$ iteration. The symbol w is used for inertia, with Ir and Ir^{max} corresponding to iteration and maximum iteration, respectively. The minimum and maximum weights, w^{min} and w^{max}, are established at fixed values of 0.9 and 0.4, respectively [11]. The parameter ρ signifies the constriction factor, with a value of 0.729, and both c^1 and c^2 are assigned values of 2.05. The $S^{personalbest}$, $S^{globalbest}$ are associated with local/personal, global/universal-best populations. The notations V and S represent the velocity and swarm positions within the APSO framework, where k stands for the k^{th} iteration, and r^1 and r^2 are random values between 0 and 1, respectively. The flowchart of APSO technique for the optimal integration of PV and D-FACTS in a modernized IEEE 69-bus reconfigured network is illustrated in Fig. 1. Three PVs, three D-FACTS devices, three locations, and all five tie-switches are converted to swarm/particle representations in process of optimization.

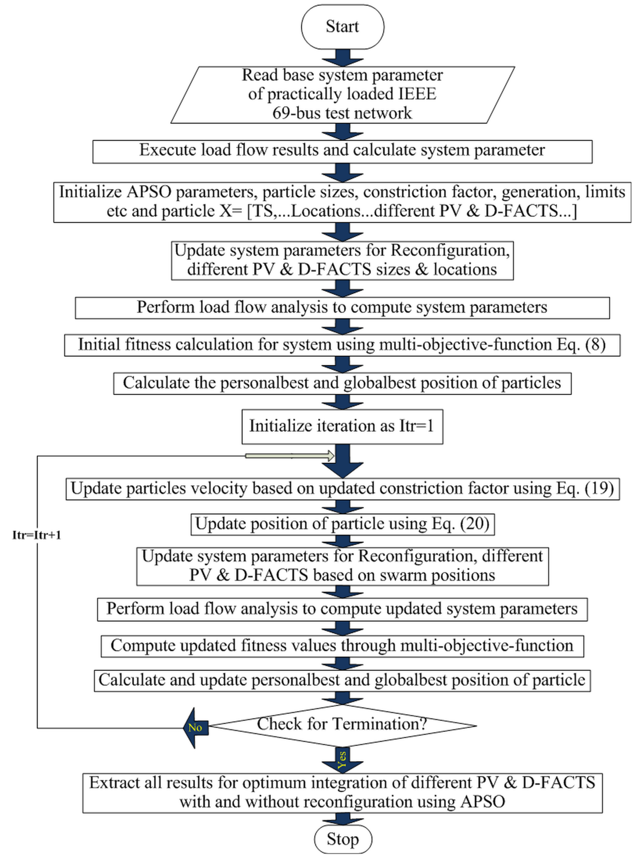

Figure 1. Flowchart of APSO technique for the planning of PV and D-FACTS with reconfiguration

4. RESULT ANALYSIS

In the proposed work, the optimum integration of multiple PV and D-FACTS in a modernized reconfigured 69-bus network is performed using the APSO based on the considered nMOF for the projected investigation. In which five objective indices (R^{Loss}, Q^{Loss}, V^{DP}, lousy R^N, and high LFC^{Level}) are regarded as objective in the nMOF.

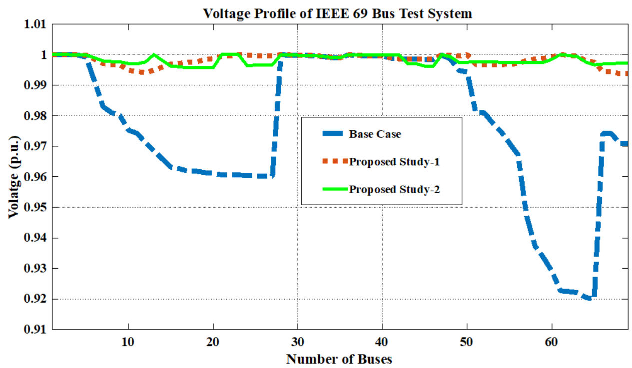

Figure 2. Enhanced voltage profile of the test system

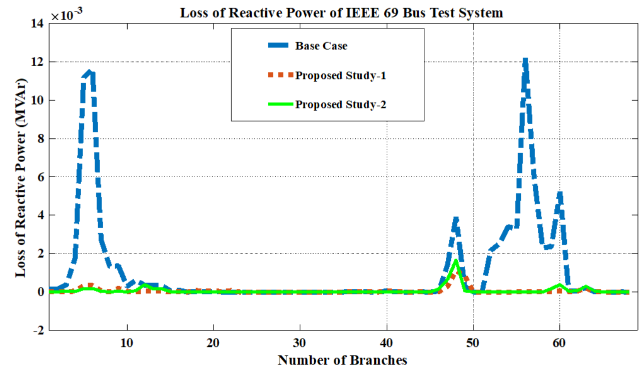

Figure 4. Reduced reactive power of the test system

TABLE III. DGs (PV AND D-FACTS) SIZES AND LOCATION

Cases	PV Size (MW)	D-FACTS Size (MVAr)	Location	TS Status
Proposed Study-1	1.71, 0.45, 1.21	0.74, 0.29, 0.30	61, 23, 50	1,1,1,1,1
Proposed Study-2	1.87, 0.64, 2.32	1.08, 0.54, 0.54	61, 13, 47	

TABLE IV. THE R^{Loss}, Q^{Loss}, S^{Loss}, V^{DP}, LFC^{Level} AND R^N

Cases	Losses in MW, MVAr, MVA			V^{DP} (p.u.)	LFC^{Level} (kA)	% R^N
	R^{Loss}	Q^{Loss}	Q^{Loss}			
Base System Study	0.1700	0.0785	0.1872	0.1800	6.6150	81.85
Proposed Study-1	0.0068	0.0049	0.0084	0.1063	0.2968	95.80
Proposed Study-2	0.0058	0.0044	0.0073	0.1043	0.0004	96.49

In the Base System Study (BS) after load flow the noticed loss in real and reactive power (R^{Loss} and Q^{Loss}) is 0.17 MW and 0.0785 MVAr. Whereas maximum V^{DP}, LFC^{Level}, and R^N is 0.1800 p.u., 6.6150 kA, and 81.85 % as given in Table IV and Fig. 2-4. The outcomes related to C^{FIX}, C^{LOSS}, and C^{AENS} are 18230.3271 \$/Year, 58986.0951 \$/Year, and 16498.8381 \$/Year, respectively, given in Table V. In this case, the CO_2 is 2471.12 kg/h, SO_2 is 10.7134 kg/h, and NO_X is 5.2394 kg/h, as seen in

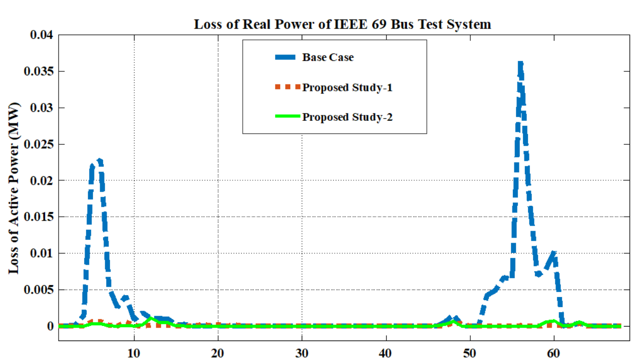

Figure 3. Reduced real power of the test system

Table VI. In continuation, after observing the BS results, two more studies have been proposed for the modernized 69-bus DS. In PS-1, the optimal integration of multiple PV and D-FACTS in a modernized 69-bus network has been performed. In PS-2, the optimal integration of multiple PV and D-FACTS in a modernized reconfigured 69-bus network has been performed.

TABLE V. DIFFERENT COST

Cases/ Different Cost (\$/Year)	C^{FIX}	C^{LOSS}	C^{AENS}	Total Cost
Base System Study	18230.3271	58986.0951	16498.8381	93715.2604
Proposed Study-1	18230.3271	2017.7376	740.3596	20988.4244
Proposed Study-2	18247.2054	2355.2039	0.901151	20603.3105

In PS-1, the optimal integration of 1.71 MW, 0.45 MW, 1.21 MW sizes of PV's and 0.74 MVAr, 0.29 MVAr, 0.30 MVAr sizes of D-FACTS are carried out at 61^{th}, 23^{rd}, and 50^{th} bus locations of the test system as illustrated in Table-III. In which it is found that the R^{Loss}, Q^{Loss}, V^{DP}, and LFC^{Level} are diminished to 0.0068 MW, 0.0049 MVAr, 0.1063 p.u. and 0.2968 kA with 95.80 % of R^N as given in Table IV, Fig. 2-4. The outcomes related to C^{FIX}, C^{LOSS}, and C^{AENS} are reduced to 18230.3271 \$/Year, 2017.7376 \$/Year, and 740.3596 \$/Year, respectively compared to the BS as seen in Table V. It is also noticed that the total cost which is comprised of C^{FIX}, C^{LOSS}, and C^{AENS} is diminished by 77.60 %. The pollutant gas emissions (PGE's) CO_2, SO_2, and NO_X are diminished to 233.84 kg/h, 1.0138 kg/h, and 0.4958 kg/h related to BS, which can be seen in Table VI.

Similarly, in PS-2, the optimal integration of 1.87 MW, 0.64 MW, 2.32 MW sizes of PV's and 1.08 MVAr, 0.54 MVAr, 0.54 MVAr sizes of D-FACTS with five active tie-switches are carried out at 61^{th}, 13^{th}, and 47^{th} bus locations of the test system as given in Table III. After this PV and D-FACTS integration, it is found that the R^{Loss}, Q^{Loss}, V^{DP},

TABLE VI. POLLUTANT GAS EMISSION (PGE) IN BS, PS-1, AND PS-2

PGE Component	PGE in BS (kg/h)	PGE in PS-1 (kg/h)	PGE in PS-2 (kg/h)
CO_2	2471.1200	233.8400	183.2800
SO_2	10.7134	1.0138	0.7946
NO_X	5.2394	0.4958	0.3886

TABLE VII. FITNESS FUNCTION

Cases	nMOF Indices					nMOF	CPU Time (Sec.)	Total Run
	IR^{Loss}	IQ^{Loss}	IV^{DP}	$ILFC^{Level}$	IR^{N}			
Proposed Study-1	0.0342	0.0567	0.0966	0.0449	0.2314	0.0756	421.3867	50000
Proposed Study-2	0.0399	0.0630	0.0948	0.0001	0.1932	0.0676	427.1038	50000

TABLE VIII. COMPARISON BETWEEN PROPOSED WORK WITH ANOTHER EXISTED WORK

Compared Work	Optimization Methods	Loss	
		Magnitude (kW)	Reduction (%)
Vempalle, et al. [3]	PSO-DA	39.2	82.57
Muhammad, et al. [4]	WCA	35.0442	84.42
Rahim, et al. [5]	FA	126.8	43.64
	EA	150.4	33.15
Kanwar, et al. [6]	TLBO	42.25	81.22
	ITLBO	39.63	82.38
Ali, et al. [19]	IDBEA	78.34	65.18
Abid, et al. [20]	AHA	11.8	94.75
Das, et al. [21]	PEM	13.73	93.89
Work Proposed	Adaptive PSO	5.8	96.59

and LFC^{Level} are diminished to 0.0058 MW, 0.0044 MVAr, 0.1043 p.u. and 0.0004 kA with 96.49 % of R^N as shown in Table IV, Fig. 2-4. The outcomes related to C^{FIX}, C^{LOSS}, and C^{AENS} are diminished to 18230.3271 \$/Year, 2355.2039 \$/Year, and 0.901151 \$/Year, respectively in comparison with the BS as mentioned in Table V. Consequently, the total cost which is comprised of C^{FIX}, C^{LOSS}, and C^{AENS} is diminished by 78.01 %. In line with this, the pollutant gas emissions (PGE's) CO_2, SO_2, and NO_X are lowered to 183.28 kg/h, 0.7946 kg/h, and 0.3886 kg/h related to BS, which can be seen from Table VI.

Finally, from the result analysis in light of the following perspective: the TEE-benefit enhancement, fitness function

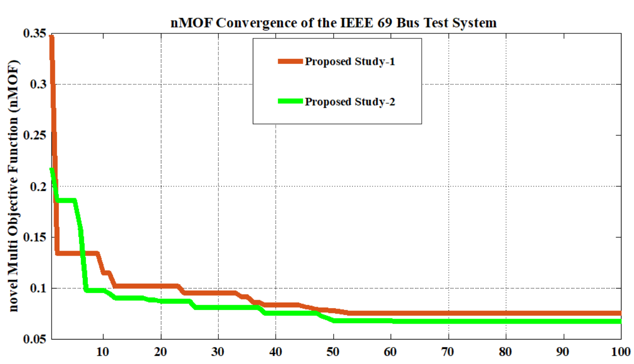

Figure 5. Convergence of the nMOF

convergence value, and computation time (CPU time) for 500 trials-run of 100 iterations as illustrated in Table-VII and Fig. 5 it can be said that the PS-2 is superior than the PS-1. The analyzed result of the PS-2 is presented in Table-VIII in comparison with other existing works.

5. CONCLUSION

In the proposed work, the optimum integration of multiple PV and D-FACTS in a modernized reconfigured 69-bus network has been performed using the APSO based on the considered nMOF for TEE-benefit improvement analysis. This has been done to provide an enriched electricity supply to the end users with improved quality and reliability. In this study, one important factor, which is the LFC^{Level} along with R^{Loss}, & Q^{Loss}, V^{DP}, and R^N, is considered as an index in the objective function, which makes the proposed MOF a novel MOF (nMOF). The cost-economic and Pollutant Gas Emissions (PGE) parameters are also examined in accordance with this nMOF optimized outcomes. Through this optimal integration of PV and D-FACTS with five active reconfiguration tie-switches, the R^{Loss}, Q^{Loss}, V^{DP}, and LFC^{Level} are diminished to 0.0058 MW, 0.0044 MVAr, 0.1043 p.u., and 0.0004 kA with 96.49 % of R^N. Then, the outcomes related to C^{FIX}, C^{LOSS}, and C^{AENS} are diminished to 18230.3271 \$/Year, 2355.2039 \$/Year, and 0.901151 \$/Year, subsequently, the total cost is diminished by 78.01 % related to the BS. In line with this, the pollutant gas emissions (PGE's) CO_2, SO_2, and NO_X are condensed to 183.28 kg/h, 0.7946 kg/h, and 0.3886 kg/h related to BS. The analysis of the implemented modernized 69-bus DS results reveals that the losses (real and reactive) are reduced with an improved balanced voltage profile and reliability. Consequently, the line fault current level is reduced. Hence, from the result analysis in light of the following perspective: the TEE-benefit improvement, nMOF convergence value, and computation time (CPU time) for 500 trials-run of 100 iterations, it can be said that the proposed work has performed better than the existing ones. Further, this work can be extended with the optimum integration of electric-vehicle charging-stations.

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