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OPTIMAL PLACEMENT OF SINGLE DG AND CAPACITORS USING MODIFIED DIRECT SEARCH ALGORITHM – Part B

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Abstract:
In this paper, Single DG and Capacitor are placed using Modified Direct Search Algorithm (MDSA). This is the continuation of Part A paper on Optimal placement of DGs implemented with Water Cycle Algorithm. DGs used in this work are same as Part A i.e., Mini Hydro DGs, Wind DGs and Solar DGs. MDSA does not start with random initialization of sizes of DGs or capacitors. MDSA offers better results compared to other artificial techniques. Discrete sizes of DGs and capacitors are used in MDSA. For example 1000kW, 500kW, 900 kVAr, 450 kVAr, 300 kVAr etc. The algorithm considers all buses as potential locations for several groups of possibilities. The algorithm is implemented on 33 Bus and 69 Bus systems along with cost analysis. Before and after implementing DG placement, CO_2 emissions have been calculated to highlight the benefits of installing DGs in the distribution system for better environment. 40% DG penetration is considered in this work voltage profiles before and after placing DGs and Capacitors have been plotted. The results obtained in this extensive research work are compared with the results obtained from WCA algorithm of Part A paper.

Keywords
Distributed Generation, Modified Direct Search Algorithm.

I. INTRODUCTION

Objective Function

To minimize the total cost 'S', an objective function is proposed as shown. The first term describes cost of energy loss and second term is the cost of DG installation and the third term is cost of capacitors.

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$$Minimum\ S = K_e \sum_{j=1}^{L} T_j P_j + \sum_{i=1}^{n} K_{DGi} P_{DGi} + \sum_{k=1}^{m} K_c Q_{ck}$$

Where K_e is the energy cost of one kWh, T_j is the duration of j_{th} level of load. Same objective function has been considered in part A work. Hence, explained in brief.

Implementation of MDSA for Optimal Placement of Single DG and Capacitors

The algorithm and flow chart of Modified Direct Search Algorithm (MDSA) [1]. MDSA is used to place DGs and capacitors whereas; DSA only deals with optimal placement of capacitors [2]. MDSA is used to determine simultaneously for optimal locations and optimal sizes of DGs in radial distribution system. Total capacity of DGs is first determined from the system data. A number of combinations with different sizes of DGs are to be tried. All possible options are enlisted. The first option is with single DG, the P (active power) of which is nearest to 40% of total kW load. According to this algorithm, the DG is placed in turn at all load buses, and for each case, power loss is determined by conducting load flow. The bus that gives minimum loss is considered as the best location for this case. In the second case, total capacity is divided into two DGs. After placing first DG at its best location, same procedure is implemented for second DG to find its optimal location. Minimum loss that can be obtained in the second case is recorded. Different sizes of DGs are considered in such a way that total DG capacity is almost equal to the 40% of total kW capacity of the entire system. From each combination, active power losses are obtained and these losses are checked with tolerance limit. If the tolerance is allowable, algorithm can be terminated. A tolerance index is defined as the absolute value of difference between active power losses obtained in any combination and minimum possible loss. A small value is assumed for tolerance index. All possible options are arranged in a sequence. For capacitor placement, Direct Search Algorithm [2] is implemented on the same lines as DGs.

II. CASE STUDIES

Analysis on 33 Bus System:

In this section, optimal placement is carried out on 33 Bus system with different types of DGs and capacitor and results are presented. Section 4.3.1.1 presents optimal placement of Solar DG and Capacitors. Section 4.3.1.2 presents optimal placement of Wind DG and Capacitors. Section 4.3.1.3 presents optimal placement of Mini Hydro DG and Capacitors. 4.3.1.4 Comparison of various DG placements using WCA. 4.3.1.5 presents the comparison of results for the placement of DGs and capacitor banks with other algorithms, 4.3.1.6 presents cost analysis and 4.3.1.7 presents the reduction in environmental pollution.

Optimal placement of Solar and Capacitor using MDSA

According to MDSA, the total DG capacity is 1500 kW and Capacitor bank capacity is 900 kVAr. Solar DG units are installed at Buses 12 and 32 and their sizes are 1000 kW and 500 kW respectively. Capacitors are installed at Buses 30, 14 and 32 their sizes are 450 kVAr, 300 kVAr and 150 kVAr respectively. Table 1 shows the comparison between WCA and MDSA algorithms for the placement of Solar DGs and Capacitors on 33 Bus System. The active power loss obtained by WCA algorithm is 48.31 kW whereas by MDSA algorithm is 46.40 kW i.e 78% reduction of original loss 211 kW. Figure 1 shows Voltage Profile before and after installation of Solar DGs and Capacitors.

Table 1: Results of optimal Solar DGs and Capacitors placement comparison for 33 Bus System

Information	WCA	MDSA
Optimal Placement of bus for Solar DGs	12 32	12 32
Size of Solar DG (kW)	938 513	1000 500
Optimal Placement of bus for Capacitors	30 14 32	30 14 32
Size of Capacitor (kVAr)	458 292 162	450 300 150
Active Power Loss (kW)	48.31	46.4

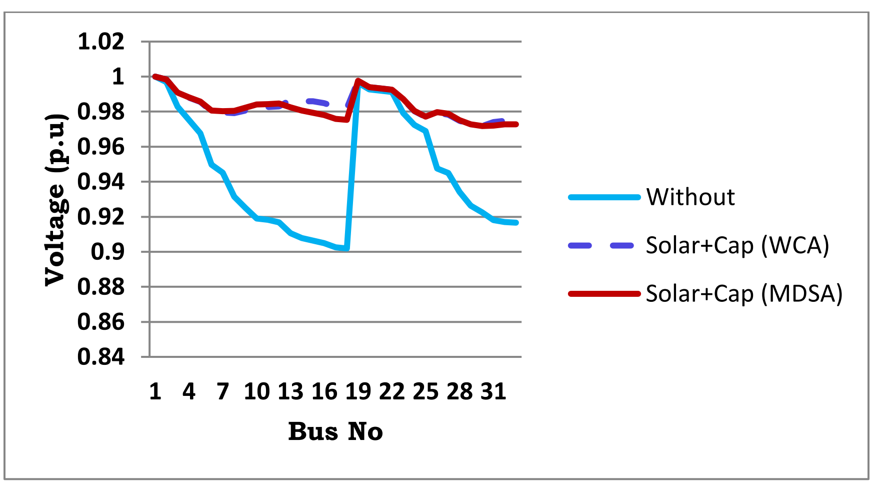

Figure 1: Voltage Profiles of without and with Compensation of Solar DGs and Capacitors

Optimal placement of Wind and Capacitor using MDSA

According to MDSA, the total DG capacity is 1500 kW and Capacitor bank capacity is 900 kVAr. Wind DG units are installed at Buses 7 and 24 and their sizes are 1000 kW and 500 kW respectively. Capacitors are installed at Buses 31, 14 and 30 their sizes are 450 kVAr, 300 kVAr and 150 kVAr respectively. Table 2 shows the comparison between WCA and MDSA algorithms for the placement of Wind DGs and Capacitors on 33 Bus System. The active power loss obtained by WCA algorithm is 118.56 kW whereas by MDSA algorithm is 110.81 kW i.e 47.4% reduction of original loss 211 kW. Fig. 2 shows Voltage Profile before and after installation of Wind DGs and Capacitors.

Table 2: Results of optimal Wind DGs and Capacitors placement comparison for 33 Bus System

Information	WCA	MDSA
Optimal Placement of bus for Wind DGs	7 24	7 24
Size of Wind DG (kW)	960 459	1000 500
Optimal Placement of bus for Capacitors	31 14 30	31 14 30
Size of Capacitor (kVAr)	401 230 133	450 300 150
Active Power Loss (kW)	118.56	110.81

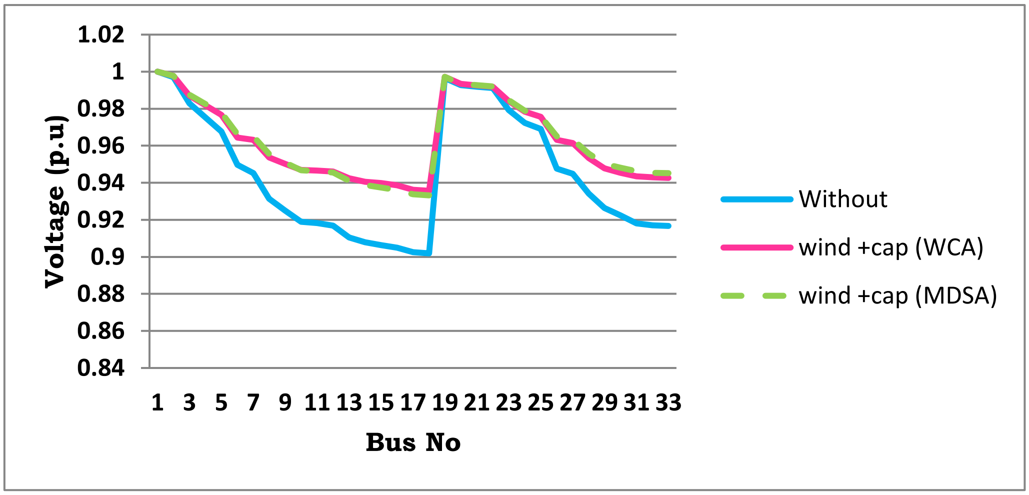

Figure 2: Voltage Profiles of without and with Compensation of Wind DGs and Capacitors

Optimal placement of Mini Hydro and Capacitor using MDSA

According to MDSA, the total DG capacity is 1500 kW and Capacitor bank capacity is 900 kVAr. Mini Hydro DG units are installed at Buses 30 and 14 and their sizes are 1000 kW and 500 kW respectively. Capacitors are installed at Buses 31, 25 and 8 their sizes are 300 kVAr, 150 kVAr and 150 kVAr respectively. Table 3 shows the comparison between WCA and MDSA algorithms for the placement of Mini Hydro DGs and Capacitors on 33 Bus System. The active power loss obtained by WCA algorithm is 38.55 kW whereas by MDSA algorithm is 33.59 kW i.e 84% reduction of original loss 211 kW. Fig. 3 shows Voltage Profile before and after installation of Mini Hydro DGs and Capacitors.

Table 3: Results of optimal Mini Hydro DGs and Capacitors placement comparison for 33 Bus System

Information	WCA	MDSA
Optimal Placement of bus for Mini Hydro DG	30 14	30 14
Size of Mini Hydro DG (kW)	983 511	1000 500
Optimal Placement of bus for Capacitor	31 25 8	31 25 8
Size of Capacitor (kVAr)	306 166 166	300 150 150
Active Power Loss (kW)	38.55	33.59

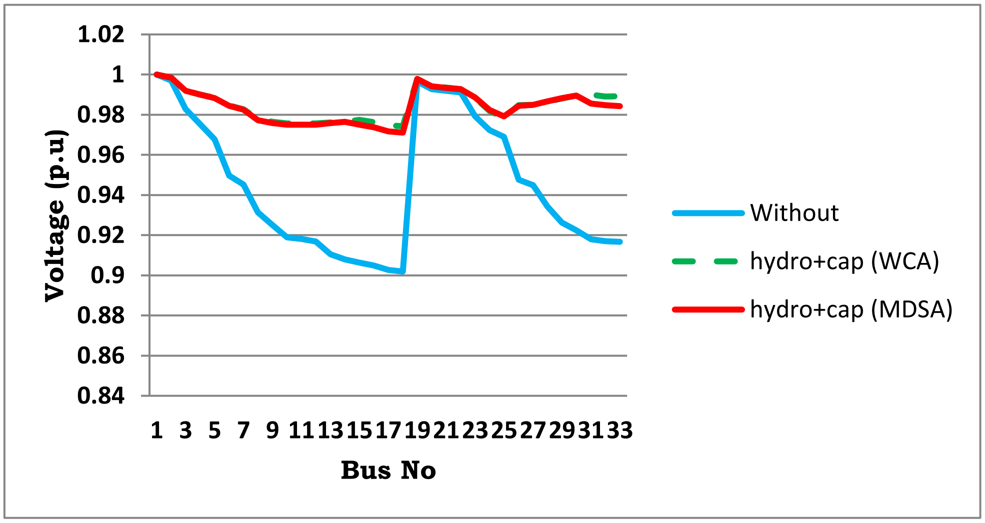

Figure 3: Voltage Profiles of without and with Compensation of Mini Hydro DGs and Capacitors

Comparison of various DG and Capacitor placements using MDSA

In this section all the three above cases are compared. Table 4 presents comparison of placement with different DGs and capacitors. DG sizes, capacitor sizes and active power losses are compared. Active power loss obtained with Solar DG and Capacitor is 46.4 kW and active power loss obtained with Wind DG and capacitors is 110.81 kW and active power loss with Mini Hydro DG and Capacitors is 33.59 kW using MDSA. Compensation with Mini Hydro DG and capacitor gives best results. Figure 4 shows Voltage Profile before and after installation of DGs and Capacitors.

Table 4: Comparison of various DG placements and Capacitors for 33 Bus system using WCA and MDSA

Information	**Solar With WCA**	**Solar with MDSA**	**Wind With WCA**	**Wind with MDSA**	**Mini Hydro With WCA**	**Mini Hydro with MDSA**
Optimal Placement of bus for DG	12 32	12 32	7 24	7 24	30 14	30 14
Size of DG (kW)	938 513	1000 500	960 459	1000 500	983 511	1000 500
Optimal Placement of bus for Capacitor	30 14 32	30 14 32	31 14 30	31 14 30	31 25 8	31 25 8
Size of Capacitor (kVAr)	458 292 162	450 300 150	401 230 133	450 300 150	306 166 166	300 150 150
Active Power Loss (kW)	48.31	46.4	118.56	110.81	38.55	33.59

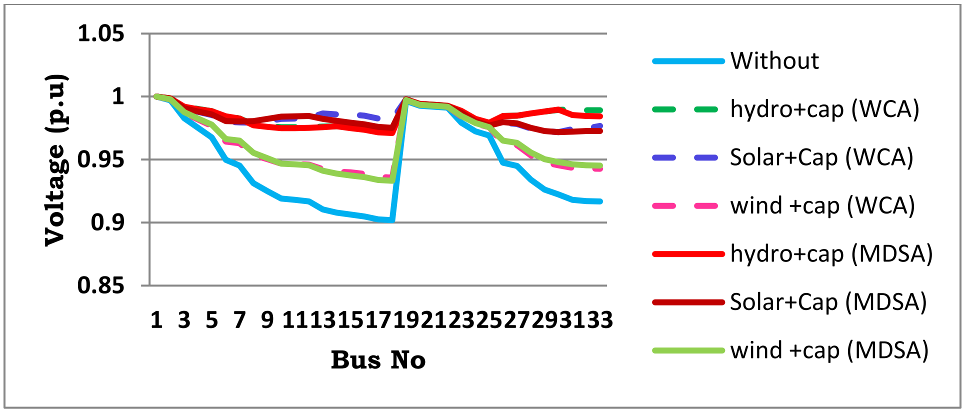

Figure 4: Voltage Profiles of without and with Compensation of DGs and Capacitors
Comparison of MDSA with other Algorithms

Optimal placement of DGs by Modified Direct Search Algorithm is compared with other algorithms like Strength Pareto Evaluation Algorithm, Multi-Objective Particle Swarm Optimization etc. [18]. In the case of Strength Pareto Algorithm [18] the three DGs are assumed to work at different power factors. They are 0.97, 0.84 and 0.829 respectively. In the case of NSGA algorithm [18], the three DGs are assumed to work at 0.87, 0.917 and 0.938 power factors respectively. Mini Hydro Power Generation units and capacitors are considered for comparison of Modified Direct Search Algorithm with other algorithms. The other assumptions considered in all the following cases are, Maximum size of DGs is 1.5MW, the least capacitor size is 150 kVAr. In the following Table 5, each column indicates one method and the top three rows indicates optimal locations of DGs and the following next three rows indicates their corresponding size of DGs obtained by the algorithm. Next few locations indicate optimal locations for capacitors and immediately followed by their sizes of capacitors in kVAr. Last row of each column indicates the active power loss after placement of DGs and capacitors.

It is observed that according to proposed MDSA which is presented in the last column the loss obtained is 33.59kW, which is lowest of all other methods. According to MDSA, the total DG capacity is 1500 kW and Capacitor bank capacity is 600 kVAr which are very less compared to any other algorithm. Mini Hydro Generators are installed at Buses 30 and 14 and their sizes are 1000 kW and 500 kW respectively. Switched Capacitors are installed at Buses 31, 25 and 8 their sizes are 300kVAr, 150kVAr and 150kVAr respectively.

Table 5: Results of optimal DGs and Capacitor placement comparison with different Algorithms

Method	SPEC [18]	NSGA [18]	ICA/GA [18]	MOPSO [18]	WCA	Proposed MDSA
Optimal Placement of bus for DG	11	9	9	9	30	30
	23	24	25	23	14	14
	33	32	33	30	--	--
Size of DG (kW)	1603	1477	1284	911	983	1000
	1980	1960	1970	669	511	500

	1960	1671	1616	1423	--	---
Optimal Placement of bus for Capacitor	2	3	2	10	31	31
	20	19	4	21	25	25
	--	33	33	--	8	8
Size of Capacitor (kVAr)	1500	1950	1200	1050	306	300
	2250	600	300	1200	166	150
	--	750	900	--	166	150
Active Power Loss (kW)	178	113.8	88.2	80.8	38.55	33.59

Cost Analysis on 33 Bus system

Cost of Energy loss is considered as US $ 0.06 per kWhr and considering the purchase of capacitor at a cost of US $ 3.0 per kVAr [2]. Cost of installation of Mini Hydro of 1 MW is assumed to be US $ 8.33 lakhs [19]. Table 6 shows system load duration time data under three load levels. i.e., 50%, 100% and 160% load levels.

Table 6: Load duration time for three load levels

Load level	0.5 (Light)	1.0 (Nominal)	1.6 (Peak)
Duration (H)	2000	5260	1500

Table 7 presents DG and capacitor placement locations and sizes. Sizes of different DGs and capacitor must be installed to meet the needs of varying loads. Table 8 presents cost of energy loss before placing DGs and capacitors. Cost of energy loss after placing DGs and capacitors for three load levels is presented in Table 9.

Table 7: Optimal DG and Capacitor placement location and size

Description	Optimal Location	Control Setting Active Power (kW)			Optimal Size (kW)	Control Setting Reactive Power (kVAr)			Optimal Size (kVAr)
		0.5	1.0	1.6		0.5	1.0	1.6	
Mini Hydro DGs	30	500	1000	1500	1500	309.8	619.7	929.6	929.61
	14	300	500	800	800	185.9	309.8	495.7	495.79
Capacitors	31	---	---	---	---	150	300	450	450
	25	---	---	---	---	150	150	300	300
	8	---	---	----	---	---	150	150	150

Table 8 Cost of energy loss before DG and Capacitor placement

Load level	0.5 (Light)	1.0 (Nominal)	1.6(Peak)
Cost of Energy loss (US $)	5,851.2	66,591.6	54,190.8

At nominal loading level, loss is US $ 66,591.6 which is more than the loss incurred during 160% loading level i.e US $ 54,190.8as the energy loss depends on the product of load duration time, power loss and energy loss cost per one kWhr.

Table 9 Cost of energy loss after DG and Capacitor placement

Load level	0.5 (Light)	1.0 (Nominal)	1.6 (Peak)
Energy loss cost (US $)	888	10,601	8,386.2

Capital investment is made to install DGs and Capacitors which is calculated as US $ 19,18,600. The total Cost of Depreciation and interest on capital investment on DGs and capacitors is taken as 10% per year which is US $ 1,91,860. Maintenance and Operation cost is taken as 6% per year [19] which is US $ 1,15,116. Total cost is the sum of energy loss cost, interest and depreciation cost of installation of DGs and capacitors and Maintenance and Operation cost of DGs.

Table 10 shows the comparison of various costs before and after DG and capacitor placement on 33 Bus system. Without DG and Capacitor placement, the energy loss cost is US $ 1,26,634. whereas after compensation it is, US $ 22,203 and US $ 19,875with WCA and MDSA algorithms respectively. There is 84.3% reduction in energy loss cost by installing DGs and capacitors using MDSA. There is a huge saving due to reduction in the purchased energy from the grid due to the installation of DGs. The cost of energy saving isUS $ 7,73,966 and US $ 7,76,400 using WCA and MDSA algorithms respectively. There was a final cost benefit of US $ 4,44,117 and US$ 4,49,549. The payback period of installing DGs is less than 10 years.

Table 10: Comparison of cost results before and after compensation using WCA and MDSA

Information	**Unit**	**Without DG and Capacitor placement**	**With DG and Capacitor placement using WCA**	**With DG and Capacitor placement using MDSA**
Energy Loss Cost	US $	1,26,634	22,203	19,875
Cost of Depreciation and interest on capital investment.	US $	0	1,92,392	1,91,860
DGs Maintenance and	US $	0	1,15,254	1,15,116

operation cost				
Saving due to reduction in purchased energy cost	US $	0	7,73,966	7,76,400
Final cost benefit	US $	---	4,44,117	4,49,549
Load level 0.5	Losses (kW)	48.76	8.73	7.4
Load level 1.0	Losses (kW)	211.0	38.55	33.59
Load level 1.6	Losses (kW)	602.12	99.88	93.18

III. REDUCTION IN ENVIRONMENTAL POLLUTION

In this section, a reduction in CO_2 emissions is calculated by the placement of DGs in 69 Bus systems. The energy produced for one year is calculated which is shown in Table 11. Out of the total energy produced, it is assumed that 60% is supplied by Thermal Power Stations. Table 11 shows, the load in terms of kW and kWh shared by DGs using WCA and MDSA algorithms. At all loading levels, it is observed that DGs given by WCA algorithm slightly take more loads compared to MDSA algorithm. Based on 0.612 kg of CO_2 emissions per kWh [20], Energy Supplied by DGs is also calculated. Out of the total energy, DGs have been assumed to substitute 60 % of Thermal and 40 % of other power generations which have no CO_2 emissions. Based on these assumptions, CO_2 emissions after placing the DGs and capacitors are calculated and also reduction of CO_2 emissions has been calculated on both systems which are presented in Table 12 for one year.

Table 11: Energy Calculation for 33 Bus system

Load Levels	No of hours	Total System load		Load shared by DGs using WCA		Load shared by DGs using MDSA	
		kW	kWh	kW	kWh	kW	kWh
0.5	2000	1857.5	37,15,000	791	15,82,000	800	16,00,000
1.0	5260	3715	1,95,40,900	1494	78,58,440	1500	78,90,000
1.6	1500	5944	89,16,000	2306	34,59,000	2300	34,50,000

Table 12: CO_2 emissions before and after DGs placement

Test Bus system	Method	CO_2 emission before DG placement (Tons)	CO_2 emission after DG placement (Tons)	Reduction in CO_2 emissions by DG placement (Tons)	Percentage of reduction in CO_2 emissions by DG placement (%)
33-Bus	WCA	11,813.52	7076.85	4736.67	40.10
	MDSA	11,813.52	7,061.95	4,751.57	40.22

Analysis on 69-Bus system

In this section, optimal placement is carried out on 33 Bus systems with different types of DGs and capacitor and results are presented. Section 4.3.2.1 presents optimal placement of Solar DG and Capacitors. Section 4.3.2.2 presents optimal placement of Wind DG and Capacitors. Section 4.3.2.3 presents optimal placement of Mini Hydro DG and Capacitors. 4.3.2.4 Comparison of various DG placements using WCA and MDSA. 4.3.2.5 presents the comparison of results for the placement of DGs and capacitor banks with other algorithms, 4.3.2.6 presents cost analysis and 4.3.2.7 presents the reduction in environmental pollution.

Optimal placement of Solar and Capacitor using MDSA

According to MDSA, the total DG capacity is 1500 kW and Capacitor bank capacity is 900 kVAr. Solar DG units are installed at Buses 61 and 64 and their sizes are 1000 kW and 500 kW respectively. Capacitors are installed at Buses 61 and 64 their sizes are 600 kVAr and 300 kVAr respectively. Table 13 shows the comparison between WCA and MDSA algorithms for the placement of Solar DGs and Capacitors on 69 Bus System. The active power loss obtained by WCA algorithm is 35.22 kW whereas by MDSA algorithm is 32.02 kW i.e 85.7% reduction of original loss 225 kW. Fig. 4.5 shows Voltage Profile before and after installation of Solar DGs and Capacitors.

Table 13 Results of optimal Solar DGs and Capacitors placement comparison for 69 Bus System

Information	WCA	MDSA
Optimal Placement of bus for Solar DGs	61 64	61 64
Size of Solar DG (kW)	1129 386	1000 500
Optimal Placement of bus for Capacitors	61 64 61	61 64 61
Size of Capacitor (kVAr)	489 293 139	450 300 150
Active Power Loss (kW)	35.22	32.02

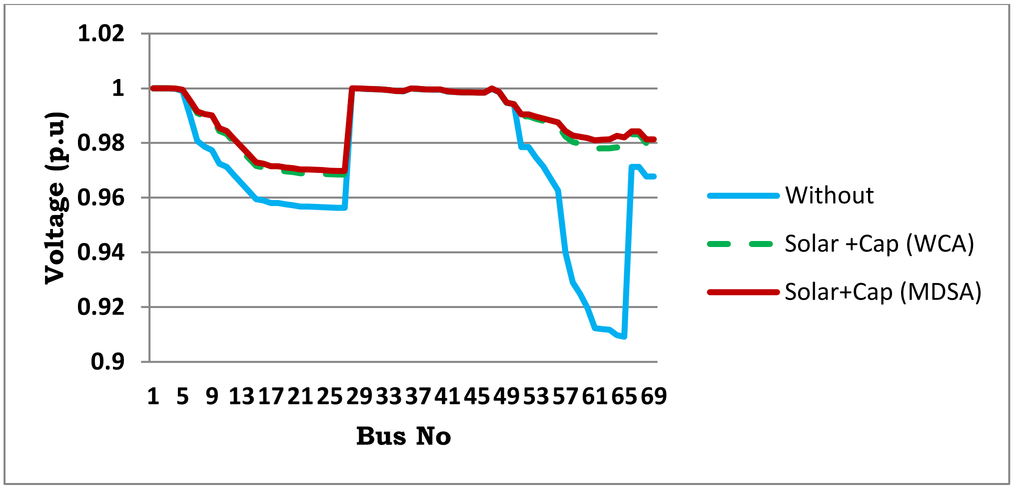

Figure 5: Voltage Profiles of without and with Compensation of Solar DGs and Capacitors

Optimal placement of Wind and Capacitor using MDSA

According to MDSA, the total DG capacity is 1500 kW and Capacitor bank capacity is 900 kVAr. Wind DG units are installed at Buses 61 and 64 and their sizes are 1000 kW and 500 kW respectively. Capacitors are installed at Buses 61 and 64 their sizes are600 kVAr and 300 kVAr respectively. Table 14 shows the comparison between WCA and MDSA algorithms for the placement of Wind DGs and Capacitors on 69 Bus System. The active power loss obtained by WCA algorithm is 94.38 kW whereas by MDSA algorithm is 92.64 kW i.e 58.8 % reduction of original loss 225 kW. Fig. 6 shows Voltage Profile before and after installation of Wind DGs and Capacitors.

Table 14: Results of optimal Wind DGs and Capacitors placement comparison for 69 Bus System

Information	WCA	MDSA
Optimal Placement of bus for Wind DGs	61 49	61 49
Size of Wind DG (kW)	1117 533	1000 500
Optimal Placement of bus for Capacitors	61 64 61	61 64 61
Size of Capacitor (kVAr)	466 276 137	450 300 150
Active Power Loss (kW)	94.38	92.64

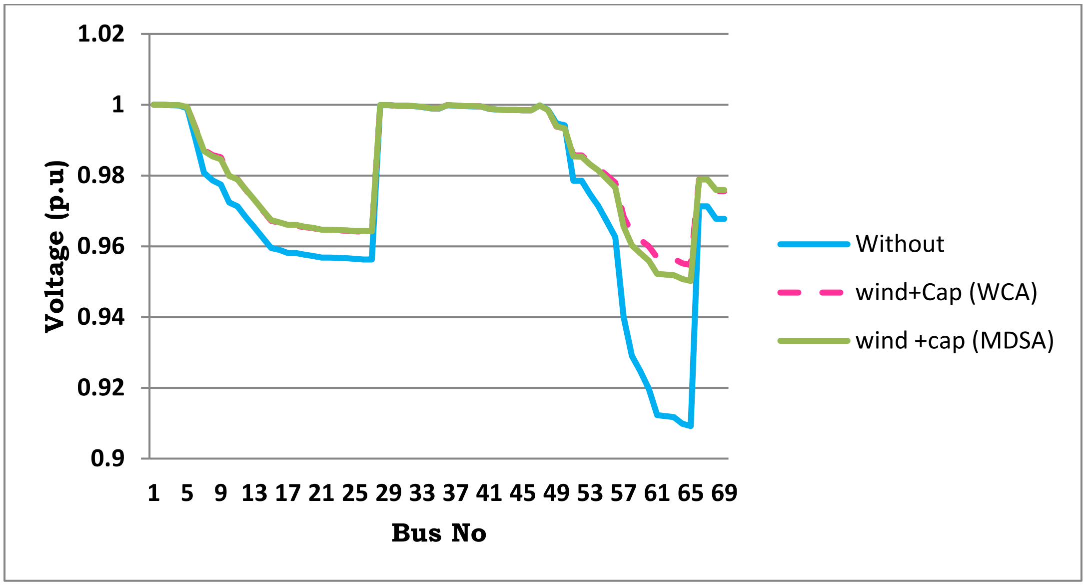

Figure 6: Voltage Profiles of without and with Compensation of Wind DGs and Capacitors
Optimal placement of Mini Hydro and Capacitor using MDSA

According to MDSA, the total DG capacity is 1500 kW and Capacitor bank capacity is 450 kVAr. Mini Hydro DG units are installed at Buses 17 and 61 and their sizes are 1000 kW and 500 kW respectively. Capacitors are installed at Buses 17 and 61 their sizes are 300 kVAr and 150 kVAr respectively.Table 15 shows the comparison between WCA and MDSA algorithms for the placement of Mini Hydro DGs and Capacitors on 69 Bus System. The active power loss obtained by WCA algorithm is 23.05 kW whereas by MDSA algorithm is 22.41 kW i.e 90% reduction of original loss 225 kW. Fig. 7 shows Voltage Profile before and after installation of Mini Hydro DGs and Capacitors.

Table 15: Results of optimal DGs and Capacitors placement comparison for 69 Bus System

Information	WCA	MDSA
Optimal Placement of bus for Mini Hydro DGs	61 64	61 64
Size of Mini Hydro DG (kW)	1013 472	1000 500
Optimal Placement of bus for Capacitors	17 61	17 61
Size of Capacitor (kVAr)	301 126	300 150
Active Power Loss (kW)	23.05	22.41

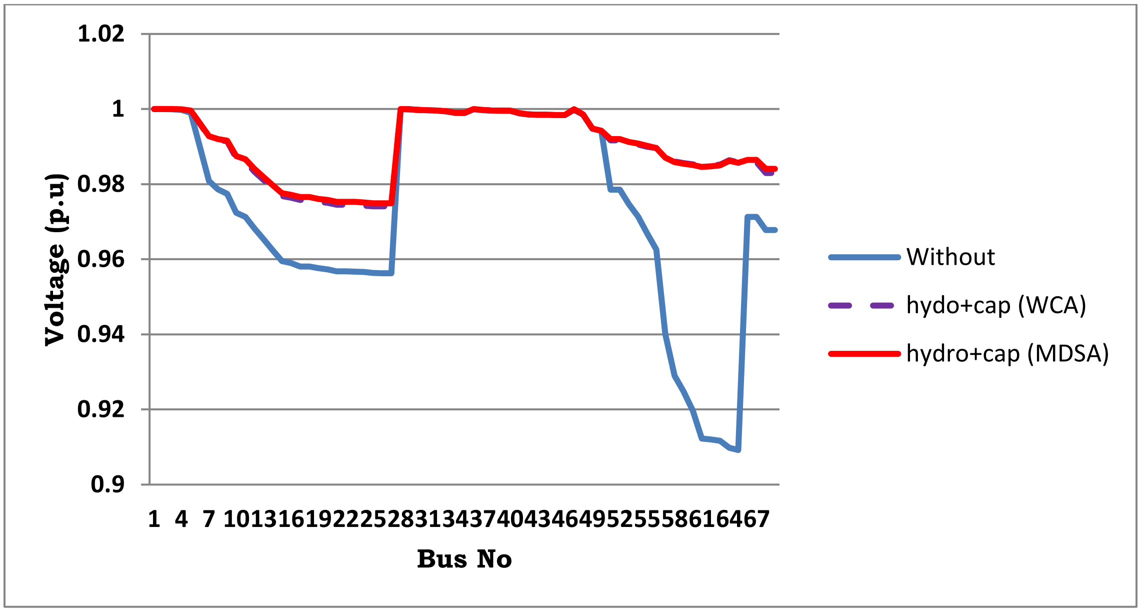

Figure 7: Voltage Profiles of without and with Compensation of Mini Hydro DGs and Capacitors

IV. COMPARISON OF VARIOUS DG AND CAPACITOR PLACEMENTS USING WCA AND MDSA

In this section all the three above cases are compared. Table 16 presents comparison of placement with different DGs and capacitors. DG sizes, capacitor sizes and active power losses are compared. Active power loss obtained with Solar DG and Capacitor is 32.02 kW and active power loss obtained with Wind DG and capacitors is 92.64 kW and active power loss with Mini Hydro and Capacitors is 22.41 kW using MDSA. Compensation with Mini Hydro and capacitor gives best results. Figure 8 shows Voltage Profile before and after installation of DGs and Capacitors.

Table 16: Comparison of various DG placements and Capacitors for 69 Bus System using WCA and MDSA

Information	Solar With WCA	Solar with MDSA	Wind With WCA	Wind with MDSA	Mini Hydro With WCA	Mini Hydro with MDSA
Optimal Placement of bus for DGs	61 64	61 64	61 49	61 49	61 64	61 64
Size of DG (kW)	1129 386	1000 500	1117 533	1000 500	1013 472	1000 500

Optimal Placement of bus for Capacitors	61 64 61	61 64 61	61 64 61	61 64 61	17 61	17 61
Size of Capacitor (kVAr)	489 293 139	450 300 150	466 276 137	450 300 150	301 126	300 150
Active Power Loss (kW)	35.22	32.02	94.38	92.64	23.05	22.41

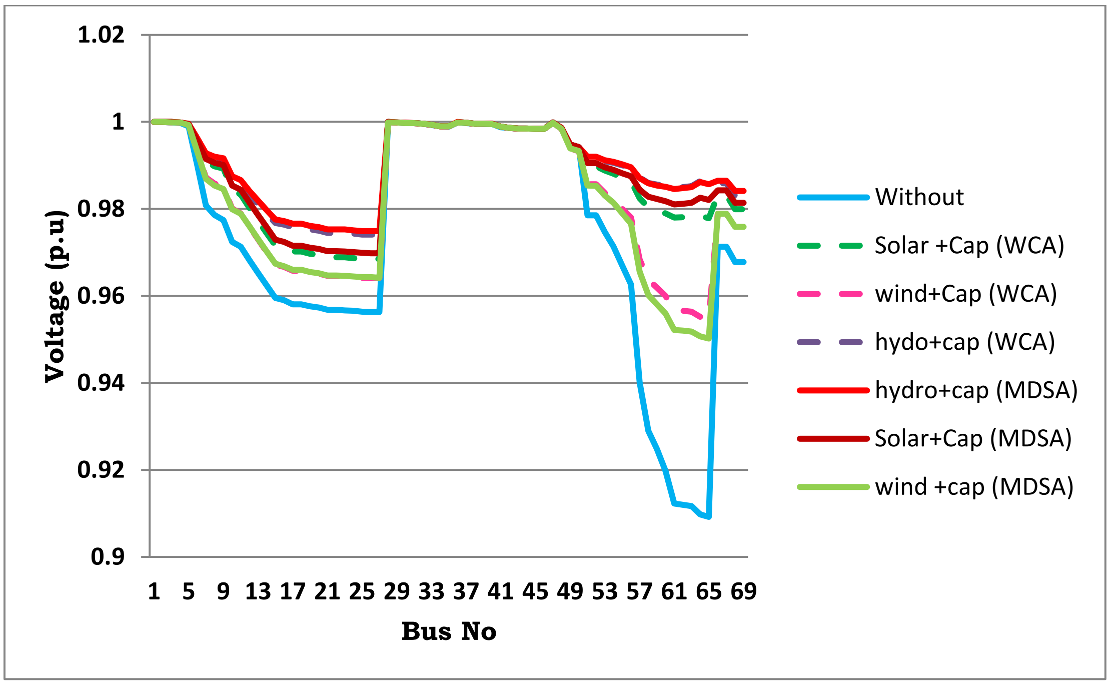

Figure 8: Voltage Profiles of without and with Compensation of DGs and Capacitors

Cost Analysis on 69 Bus system

Energy loss cost, purchase cost of capacitors and DGs have been mentioned in section 4.3.1Table 17 presents' optimal sizes of Mini Hydro DGs and Capacitor banks.

Table 17: Optimal location and size of DGs and capacitors for 69 Bus System

Description	Optimal Location	Control Setting Active Power (kW)			Optimal Size (kW)	Control Setting Reactive Power (kVAr)			Optimal Size (kVAr)
		0.5	1.0	1.6		0.5	1.0	1.6	
Mini Hydro DGs	61 64	500 300	1000 500	1500 800	1500 800	309.8 185.9	619.7 309.8	929.6 495.7	929.61 495.79

Capacitors	17	---	---	---	---	---	300	450	450
	61	---	---	---	---	---	150	300	300

By implementing MDSA algorithm, the cost of energy loss is lower in all three different loading levels after DG and capacitor placement. Cost of energy loss before and after DG and Capacitor placement and the effectiveness of MDSA algorithm can be observed from Table 18.

Table 18: Cost of energy loss before and after DG and Capacitor placement for 69 Bus System

DG and Capacitor placement	0.5 (Light)	1.0 (Nominal)	1.6 (Peak)
Before placement	6,192	71,010	58,725
After placement	830.40	7,072.6	5,686.2

Table 19 presents Comparison of various costs before and after DG and capacitor placement on 69 bus system. The energy loss cost before compensation is US$ 1,35,92 whereas after compensation it is, US $ 13,920 and US $ 13,589 with WCA and MDSA algorithms respectively. Interest and depreciation costs on capital investment are US $ 1,90,643 and US $ 1,91,815 using the two algorithms. There is a huge saving due to a reduction in the purchased energy from the grid due to the installation of DGs. The cost of energy saving is US $ 7,68,126 and US$ 7,76,400 using WCA and MDSA algorithms respectively. There is a final cost benefit of US$ 4,49,309 and US $4,56,042 using the WCA and MDSA algorithms.

Table 19 Comparison of cost results before and after compensation for 69 Bus system

Information	Unit	Without DG and Capacitor placement	With DG and Capacitor placement using WCA	With DG and Capacitor placement using MDSA
Energy Loss Cost	US $	1,35,927	13,920	13,589
Cost of Depreciation and interest on capital investment.	US $	---	1,90,643	1,91,815
Operation & Maintenance Cost	US $	---	1,14,254	1,14,954
Saving due to reduction in purchased energy	US $	---	7,68,126	7,76,400
Final cost benefit	US $	---	4,49,309	4,56,042
Load level 0.5	Losses (kW)	51.6	7.15	6.92
Load level 1.0	Losses (kW)	225	23.05	22.41

Load level 1.6	Losses (kW)	652.5	64.3	63.18

Environmental Protection through Pollution Reduction

In this section, a reduction in CO_2 emissions is calculated by the placement of DGs in 69 Bus system. The energy produced for one year is calculated which is shown in Table 20. Out of the total energy produced, it is assumed that 60% is supplied by Thermal Power Stations. Table 20 shows, the load in terms of kW and kWh shared by DGs using WCA and MDSA algorithms. At all loading levels, it is observed that DGs given by WCA algorithm slightly take more loads compared to MDSA algorithm. Energy Supplied by DGs is also calculated. Out of the total energy, DGs have been assumed to substitute 60 % of Thermal and 40 % of other power generations which have no CO_2 emissions. Based on these assumptions, CO_2 emissions after placing the DGs and capacitors are calculated and also reduction of CO_2 emissions has been calculated on both systems which are presented in Table 21 for one year.

Table 20: Energy Calculation for 69 Bus System

Load Levels	No of hours	Total System load		Load shared by DGs using WCA		Load shared by DGs using MDSA	
		kW	kWh	kW	kWh	kW	kWh
0.5	2000	1,901.1	38,02,200	781	15,62,000	800	16,00,000
1.0	5260	3,802.2	1,99,99,519	1485	78,11,100	1500	78,90,000
1.6	1500	6,083.5	91,25,250	2286	34,29,000	2300	34,50,000

Table 21: CO_2 emissions before and after DGs placement

Test Bus system	Method	CO_2 emission before DG placement (Tons)	CO_2 emission after DG placement (Tons)	Reduction in CO_2 emissions by DG placement (Tons)	Percentage of reduction in CO_2 emissions by DG placement (%)
69-Bus	WCA	12,090.71	7,38.78	4700.93	38.88
	MDSA	12,090.71	7339.14	4751.57	39.30

V. CONCLUSION

MDSA is implemented on standard 33 Bus and 69 Bus distribution systems with Solar, Wind and mini hydro distributed generators and Capacitors. One type of DG and capacitors are placed separately in each case. Results obtained by MDSA are compared with the results obtained from WCA algorithm. Proposed MDSA method is proved to be better than WCA. Placement of Mini Hydro with capacitors yields the best results compared to the other two cases. The cost analysis is carried out on the best case out of the three types of DG placements on both 33 and 69 Bus systems. Three different load levels 50%, 100%, 160% are considered to carry out cost analysis.

Active power losses are reduced and voltage profiles are improved after placement of DGs and Capacitors. With the usage of DGs, reduction in environmental pollution is calculated on both the systems. On 33 bus system, percentage reduction in CO_2 is 40.22 where as in 69 bus system, it is 39.30.

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