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Factual power loss reduction by dynamic membrane evolutionary algorithm

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ABSTRACT

This paper presents a dynamic membrane evolutionary algorithm (DMEA) that has been applied to solve optimal reactive power problems. The proposed methodology merges the fusion and division rules of P systems with active membranes and with adaptive differential evolution (ADE), particle swarm optimization (PSO) exploration stratagem. All elementary membranes are amalgamated into one membrane in the computing procedure. Furthermore, the integrated membrane is alienated into the elementary membranes 1, 2, _, *m*. In particle swarm optimization (PSO) C_1 and C_2 (acceleration constants) are vital parameters to augment the exploration ability of PSO in the period of the optimization procedure. In this work, Gaussian probability distribution is initiated to engender the accelerating coefficients of PSO. The proposed DMEA has been tested in standard IEEE 14, 30, 57, 118, and 300 bus test systems and simulation results show the projected algorithm reduced the real power loss comprehensively.

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1. INTRODUCTION

Reactive power problem plays a key role in secure and economic operations of power system. Optimal reactive power problem has been solved by variety of types of methods [1]-[6]. Nevertheless, numerous scientific difficulties are found while solving problem due to an assortment of constraints. Evolutionary techniques [7]-[16] are applied to solve the reactive power problem, but the main problem is many algorithms get stuck in local optimal solution & failed to balance the exploration & exploitation during the search of global solution. In this paper, dynamic membrane evolutionary algorithm (DMEA) has been applied to solve optimal reactive power problem. Proposed methodology merges the fusion and division rules of P systems with active membranes and with adaptive differential evolution (ADE), particle swarm optimization (PSO) exploration stratagem. In this work, composition of the dynamic membrane algorithm along with the fusion, division rules are utilized to solve the optimal reactive power problem. In skin membrane 0, elementary membranes 1, 2, _, m are embedded in the structure, and it contains set of evolutionary, communication rules, multi-set of objects. All elementary membranes are amalgamated into one membrane in the computing procedure.

Furthermore, integrated membrane is alienated into the elementary membranes 1, 2, _, m. In particle swarm optimization (PSO), C_1, C_2 (acceleration constants) are vital parameters to augment the exploration ability of PSO in the period of the optimization procedure. Conversely, dissimilar optimization problems have altered values for the acceleration constants, it will not be an effortless assignment to choose the optimal values. In this work, Gaussian probability distribution is initiated to engender the accelerating coefficients of PSO. Particle swarm optimization (PSO) based on Gaussian distribution will be employed concurrently in area from 1 to m. The proposed dynamic membrane evolutionary algorithm (DMEA) has been tested in standard IEEE 14, 30, 57, 118, and 300 bus test system and simulation results show the projected algorithm reduced the real power loss extensively.

2. PROBLEM FORMULATION

Objective of the problem is to reduce the true power loss as (1).

$$F= P_L = \sum_{k\in Nbr} g_k \left(V_i^2 + V_j^2 - 2V_i V_j \cos\theta_{ij}\right) \quad (1)$$

Voltage deviation given as (2).

$$F = P_L + \omega_v \times \text{Voltage Deviatio} \quad (2)$$

Voltage deviation given by (3).

$$\text{Voltage Deviation} = \sum_{i=1}^{Npq} |V_i - 1| \quad (3)$$

Constraint (Equality).

$$P_G = P_D + P_L \quad (4)$$

Constraints (Inequality).

$$P_{gslack}^{min} \le P_{gslack} \le P_{gslack}^{max} \quad (5)$$

$$Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max}, i \in N_g \quad (6)$$

$$V_i^{min} \le V_i \le V_i^{max}, i \in N \quad (7)$$

$$T_i^{min} \le T_i \le T_i^{max}, i \in N_T \quad (8)$$

$$Q_c^{min} \le Q_c \le Q_C^{max}, i \in N_C \quad (9)$$

3. DYNAMIC MEMBRANE EVOLUTIONARY ALGORITHM

In membrane computing, P systems with dynamic membranes are a very blistering research topic and the analogous membrane algorithms have been used extensively to solve various types of optimization problems [17]. In this work, composition of the dynamic membrane algorithm along with the fusion, division rules are utilized to solve the optimal reactive power problem. In skin membrane 0, elementary membranes 1, 2, _, *m* are embedded in the structure, and it contains set of evolutionary, communication rules, multi-set of objects. All elementary membranes are amalgamated into one membrane in the computing procedure. Furthermore, integrated membrane is alienated into the elementary membranes 1, 2, _, *m*. Proposed methodology merges the fusion and division rules of P systems with active membranes and with adaptive differential evolution (ADE), particle swarm optimization (PSO) exploration stratagem.

a. One level membrane structure has been specified
b. In particle swarm optimization (PSO), C_1, C_2 (acceleration constants) are vital parameters to augment the exploration ability of PSO in the period of the optimization procedure. Conversely, dissimilar optimization problems have altered values for the acceleration constants, it will not be an effortless assignment to choose the optimal values. In this work, Gaussian probability distribution is initiated to engender the accelerating coefficients of PSO. Particle swarm optimization (PSO) based on Gaussian distribution will be employed concurrently in area from 1 to m.
   − Start
   − Position and velocity are initialized

− Compute the fitness value
− Pbest and Gbest are updated
− If stop criterion satisfied, then end or else update Position and velocity go to step iii
− End

$$v_{i,j}^{k+1} = |randomn( )| \times \left(Pbest_{i,j}^{k} - x_{i,j}^{k}\right) + |randomn( )| \times \left(Gbest_{i,j}^{k} - x_{i,j}^{k}\right) \quad (10)$$

$$x_{i,j}^{k+1} = x_{i,j}^{k} + v_{i,j}^{k+1} \quad (11)$$

c. Execute the integration process, all elementary membranes are amalgamated into one elementary membrane one m_{one} and all elementary membranes strings are gone into the membrane m_{one}.
d. In $\mathrm{m_{one}}$ membrane, adaptive differential evolution is utilized to modernize the strings object. In this work self-adaptive method is used to control the parameters CR and F.

$$CR_i(t) = CR_{i1}(t) + N(0,1) \times \left(CR_{i2}(t) - CR_{i3}(t)\right) \quad (12)$$

$$F_i(t) = F_{i4}(t) + N(0,0.5) \times \left(F_{i5}(t) - F_{i6}(t)\right) \quad (13)$$

− Engender the preliminary population
− For each individual in the population, engender three arbitrary different integers $\mathrm{r_1, r_2}$ and $\mathrm{r_3} \in \{1,2,..,\mathrm{N}\}$ and engender an arbitrary integer $\mathrm{J_{random}} \in \{1,2,.,\mathrm{n}\}$
− If $\mathrm{random_J}(0,1) < \mathrm{CR}$ then $\mathrm{x'_{i,j} = x_{i,r3} + F * \left(x_{i,r1} - x_{i,r2}\right)}$
− Else $\mathrm{x'_{i,j} = x_{i,j}}$
− End if
− End for
− If $\mathrm{Fitenss(x'_i) \leq Fitness(x_i)}$; then $\mathrm{x_i = x'_i}$
− End if
− End for
− End condition

When $x'_{i,j}$infringe the boundary constraint, and then the violated variable value is brought back by,

$$x'_{i,j} = \begin{cases} x_{min,j} if(\, random \, ( ) \leq 0.5) \vee \left(x'_{i,j} < x_{minimum,j}\right) \\ x_{max,j} if(\, random \, ( ) \leq 0.5) \vee \left(x'_{i,j} < x_{maximum,j}\right) \\ 2 \times x_{min,j} - x'_{i,j} \; if(\, random \, ( ) > 0.5) \vee \left(x'_{i,j} < x_{minimum,j}\right) \\ 2 \times x_{min,j} - x'_{i,j} \; if(\, random \, ( ) > 0.5) \vee \left(x'_{i,j} < x_{maximum,j}\right) \end{cases} \quad (14)$$

e. By using fitness function compute the fitness of each string
f. Employ the contact rules, a replica of the most excellent strings is chosen in the membrane $\mathrm{m_{one}}$ which will be sent to the skin membrane, and the present most excellent strings are accumulated in the skin membrane.
g. Once the end condition is met, subsequently output the results; otherwise go to Step h.
h. With the m elementary membranes $\mathrm{m_{one}}$ Membrane is alienated into the identical structure. At present most excellent strings and $N_s - 1$ strings with the poor fitness will be send to every elementary membrane in roll by the send-in contact rules, and then go back to Step b.
i. End condition is the utmost number of iterations. Algorithm will end if the utmost number of iterations is reached and output the results.

4. SIMULATION RESULTS

At first in standard IEEE 14 bus system the validity of the proposed dynamic membrane evolutionary algorithm (DMEA) has been tested. Table 1 shows the constraints of control variables. Table 2 shows the limits of reactive power generators and comparison results are presented in Table 3.

Table 1. Constraints of control variables

System	Variables	Minimum (PU)	Maximum (PU)
IEEE 14 Bus	Generator Voltage	0.95	1.1
	Transformer Tap	o.9	1.1
	VAR Source	0	0.20

Table 2. Constrains of reactive power generators

System	Variables	Q Minimum (PU)	Q Maximum (PU)
IEEE 14 Bus	1	0	10
	2	-40	50
	3	0	40
	6	-6	24
	8	-6	24

Table 3. Simulation results of IEEE −14 system

Control variables	Base case	MPSO [18]	PSO [18]	EP [18]	SARGA [18]	DMEA
VG−1	1.060	1.100	1.100	NR*	NR*	1.020
VG−2	1.045	1.085	1.086	1.029	1.060	1.041
VG−3	1.010	1.055	1.056	1.016	1.036	1.052
VG−6	1.070	1.069	1.067	1.097	1.099	1.060
VG−8	1.090	1.074	1.060	1.053	1.078	1.024
Tap 8	0.978	1.018	1.019	1.04	0.95	0.961
Tap 9	0.969	0.975	0.988	0.94	0.95	0.952
Tap 10	0.932	1.024	1.008	1.03	0.96	0.908
QC−9	0.19	14.64	0.185	0.18	0.06	0.162
PG	272.39	271.32	271.32	NR*	NR*	271.02
QG (Mvar)	82.44	75.79	76.79	NR*	NR*	74.98
Reduction in PLoss (%)	0	9.2	9.1	1.5	2.5	18.095
Total PLoss (Mw)	13.550	12.293	12.315	13.346	13.216	11.098

NR* - Not reported.

Then the proposed dynamic membrane evolutionary algorithm (DMEA) has been tested, in IEEE 30 Bus system. Table 4 shows the constraints of control variables. Table 5 shows the limits of reactive power generators and comparison results are presented in Table 6.

Then the proposed dynamic membrane evolutionary algorithm (DMEA) has been tested, in IEEE 57 Bus system. Table 7 shows the constraints of control variables. Table 8 shows the limits of reactive power generators and comparison results are presented in Table 9.

Then the proposed dynamic membrane evolutionary algorithm (DMEA) has been tested, in IEEE 118 Bus system. Table 10 shows the constraints of control variables and comparison results are presented in Table 11. Then IEEE 300 bus system [19] is used as test system to validate the performance of the dynamic membrane evolutionary algorithm (DMEA). Table 12 shows the comparison of real power loss obtained after optimization.

Table 4. Constraints of control variables

System	Variables	Minimum (PU)	Maximum (PU)
IEEE 30 Bus	Generator Voltage	0.95	1.1
	Transformer Tap	o.9	1.1
	VAR Source	0	0.20

Table 5. Constrains of reactive power generators

System	Variables	Q Minimum (PU)	Q Maximum (PU)
IEEE 30 Bus	1	0	10
	2	-40	50
	5	-40	40
	8	-10	40
	11	-6	24
	13	-6	24

Table 6. Simulation results of IEEE −30 system

Control variables	Base case	MPSO [18]	PSO [18]	EP [18]	SARGA [18]	DMEA
VG−1	1.060	1.101	1.100	NR*	NR*	1.010
VG−2	1.045	1.086	1.072	1.097	1.094	1.032
VG−5	1.010	1.047	1.038	1.049	1.053	1.042
VG−8	1.010	1.057	1.048	1.033	1.059	1.026
VG−12	1.082	1.048	1.058	1.092	1.099	1.068
VG-13	1.071	1.068	1.080	1.091	1.099	1.080
Tap11	0.978	0.983	0.987	1.01	0.99	0.934
Tap12	0.969	1.023	1.015	1.03	1.03	0.946
Tap15	0.932	1.020	1.020	1.07	0.98	0.920
Tap36	0.968	0.988	1.012	0.99	0.96	0.916
QC10	0.19	0.077	0.077	0.19	0.19	0.079
QC24	0.043	0.119	0.128	0.04	0.04	0.126
PG (MW)	300.9	299.54	299.54	NR*	NR*	298.32
QG (Mvar)	133.9	130.83	130.94	NR*	NR*	130.04
Reduction in PLoss (%)	0	8.4	7.4	6.6	8.3	12.13
Total PLoss (Mw)	17.55	16.07	16.25	16.38	16.09	15.42

NR* - Not reported.

Table 7. Constraints of control variables

System	Variables	Minimum (PU)	Maximum (PU)
IEEE 57 Bus	Generator Voltage	0.95	1.1
	Transformer Tap	o.9	1.1
	VAR Source	0	0.20

Table 8. Constrains of reactive power generators

System	Variables	Q Minimum (PU)	Q Maximum (PU)
IEEE 57 Bus	1	-140	200
	2	-17	50
	3	-10	60
	6	-8	25
	8	-140	200
	9	-3	9
	12	-150	155

Table 9. Simulation results of IEEE −57 system

Control variables	Base case	MPSO [18]	PSO [18]	CGA [18]	AGA [18]	DMEA
VG 1	1.040	1.093	1.083	0.968	1.027	1.021
VG 2	1.010	1.086	1.071	1.049	1.011	1.048
VG 3	0.985	1.056	1.055	1.056	1.033	1.031
VG 6	0.980	1.038	1.036	0.987	1.001	1.030
VG 8	1.005	1.066	1.059	1.022	1.051	1.048
VG 9	0.980	1.054	1.048	0.991	1.051	1.026
VG 12	1.015	1.054	1.046	1.004	1.057	1.060
Tap 19	0.970	0.975	0.987	0.920	1.030	0.962
Tap 20	0.978	0.982	0.983	0.920	1.020	0.946
Tap 31	1.043	0.975	0.981	0.970	1.060	0.969
Tap 35	1.000	1.025	1.003	NR*	NR*	1.012
Tap 36	1.000	1.002	0.985	NR*	NR*	1.000
Tap 37	1.043	1.007	1.009	0.900	0.990	1.003
Tap 41	0.967	0.994	1.007	0.910	1.100	0.990
Tap 46	0.975	1.013	1.018	1.100	0.980	1.010
Tap 54	0.955	0.988	0.986	0.940	1.010	0.980
Tap 58	0.955	0.979	0.992	0.950	1.080	0.964
Tap 59	0.900	0.983	0.990	1.030	0.940	0.979
Tap 65	0.930	1.015	0.997	1.090	0.950	1.010
Tap 66	0.895	0.975	0.984	0.900	1.050	0.972
Tap 71	0.958	1.020	0.990	0.900	0.950	1.019
Tap 73	0.958	1.001	0.988	1.000	1.010	1.000
Tap 76	0.980	0.979	0.980	0.960	0.940	0.973
Tap 80	0.940	1.002	1.017	1.000	1.000	1.000
QC 18	0.1	0.179	0.131	0.084	0.016	0.171
QC 25	0.059	0.176	0.144	0.008	0.015	0.170
QC 53	0.063	0.141	0.162	0.053	0.038	0.140
PG (MW)	1278.6	1274.4	1274.8	1276	1275	1269.1
QG (Mvar)	321.08	272.27	276.58	309.1	304.4	269.26
Reduction in PLoss (%)	0	15.4	14.1	9.2	11.6	20.72
Total PLoss (Mw)	27.8	23.51	23.86	25.24	24.56	22.04

NR* - Not reported.

Table 10. Constraints of control variables

System	Variables	Minimum (PU)	Maximum (PU)
IEEE 118 Bus	Generator Voltage	0.95	1.1
	Transformer Tap	o.9	1.1
	VAR Source	0	0.20

Table 11. Simulation results of IEEE −118 system

Control variables	Base case	MPSO [18]	PSO [18]	PSO [18]	CLPSO [18]	DMEA
VG 1	0.955	1.021	1.019	1.085	1.033	1.010
VG 4	0.998	1.044	1.038	1.042	1.055	1.062
VG 6	0.990	1.044	1.044	1.080	0.975	1.051
VG 8	1.015	1.063	1.039	0.968	0.966	1.072
VG 10	1.050	1.084	1.040	1.075	0.981	1.012
VG 12	0.990	1.032	1.029	1.022	1.009	1.020
VG 15	0.970	1.024	1.020	1.078	0.978	1.021
VG 18	0.973	1.042	1.016	1.049	1.079	1.040
VG 19	0.962	1.031	1.015	1.077	1.080	1.027
VG 24	0.992	1.058	1.033	1.082	1.028	1.049
VG 25	1.050	1.064	1.059	0.956	1.030	1.060
VG 26	1.015	1.033	1.049	1.080	0.987	1.046
VG 27	0.968	1.020	1.021	1.087	1.015	0.910
VG31	0.967	1.023	1.012	0.960	0.961	0.932
VG 32	0.963	1.023	1.018	1.100	0.985	0.959
VG 34	0.984	1.034	1.023	0.961	1.015	1.016
VG 36	0.980	1.035	1.014	1.036	1.084	1.021
VG 40	0.970	1.016	1.015	1.091	0.983	0.980
VG 42	0.985	1.019	1.015	0.970	1.051	1.002
VG 46	1.005	1.010	1.017	1.039	0.975	1.020
VG 49	1.025	1.045	1.030	1.083	0.983	1.006
VG 54	0.955	1.029	1.020	0.976	0.963	0.969
VG 55	0.952	1.031	1.017	1.010	0.971	0.990
VG56	0.954	1.029	1.018	0.953	1.025	0.971
VG 59	0.985	1.052	1.042	0.967	1.000	0.969
VG 61	0.995	1.042	1.029	1.093	1.077	0.990
VG 62	0.998	1.029	1.029	1.097	1.048	0.992
VG 65	1.005	1.054	1.042	1.089	0.968	1.004
VG 66	1.050	1.056	1.054	1.086	0.964	1.024
VG 69	1.035	1.072	1.058	0.966	0.957	1.068
VG 70	0.984	1.040	1.031	1.078	0.976	1.031
VG 72	0.980	1.039	1.039	0.950	1.024	1.028
VG 73	0.991	1.028	1.015	0.972	0.965	1.019
VG 74	0.958	1.032	1.029	0.971	1.073	1.015
VG 76	0.943	1.005	1.021	0.960	1.030	1.004
VG 77	1.006	1.038	1.026	1.078	1.027	1.026
VG 80	1.040	1.049	1.038	1.078	0.985	1.004
VG 85	0.985	1.024	1.024	0.956	0.983	1.010
VG 87	1.015	1.019	1.022	0.964	1.088	1.020
VG 89	1.000	1.074	1.061	0.974	0.989	1.060
VG 90	1.005	1.045	1.032	1.024	0.990	1.032
VG 91	0.980	1.052	1.033	0.961	1.028	1.041
VG 92	0.990	1.058	1.038	0.956	0.976	1.036
VG 99	1.010	1.023	1.037	0.954	1.088	1.019
VG 100	1.017	1.049	1.037	0.958	0.961	1.028
VG 103	1.010	1.045	1.031	1.016	0.961	1.030
VG 104	0.971	1.035	1.031	1.099	1.012	1.026
VG 105	0.965	1.043	1.029	0.969	1.068	1.052
VG 107	0.952	1.023	1.008	0.965	0.976	1.031
VG 110	0.973	1.032	1.028	1.087	1.041	1.028
VG 111	0.980	1.035	1.039	1.037	0.979	1.026
VG 112	0.975	1.018	1.019	1.092	0.976	1.091
VG 113	0.993	1.043	1.027	1.075	0.972	1.030
VG 116	1.005	1.011	1.031	0.959	1.033	1.001
Tap 8	0.985	0.999	0.994	1.011	1.004	0.950
Tap 32	0.960	1.017	1.013	1.090	1.060	1.007
Tap 36	0.960	0.994	0.997	1.003	1.000	0.964
Tap 51	0.935	0.998	1.000	1.000	1.000	0.958
Tap 93	0.960	1.000	0.997	1.008	0.992	1.001
Tap 95	0.985	0.995	1.020	1.032	1.007	0.990
Tap 102	0.935	1.024	1.004	0.944	1.061	1.020
Tap 107	0.935	0.989	1.008	0.906	0.930	0.972

Table 11. Simulation results of IEEE −118 system *(Continued)*

Control variables	Base case	MPSO [18]	PSO [18]	PSO [18]	CLPSO [18]	DMEA
Tap 127	0.935	1.010	1.009	0.967	0.957	1.000
QC 34	0.140	0.049	0.048	0.093	0.117	0.029
QC 44	0.100	0.026	0.026	0.093	0.098	0.018
QC 45	0.100	0.196	0.197	0.086	0.094	0.189
QC 46	0.100	0.117	0.118	0.089	0.026	0.126
QC 48	0.150	0.056	0.056	0.118	0.028	0.046
QC 74	0.120	0.120	0.120	0.046	0.005	0.134
QC 79	0.200	0.139	0.140	0.105	0. 148	0.127
QC 82	0.200	0.180	0.180	0.164	0.194	0.176
QC 83	0.100	0.166	0.166	0.096	0.069	0.159
QC 105	0.200	0.189	0.190	0.089	0.090	0.172
QC 107	0.060	0.128	0.129	0.050	0.049	0.114
QC 110	0.060	0.014	0.014	0.055	0.022	0.026
PG(MW)	4374.8	4359.3	4361.4	NR*	NR*	4430.2
QG(MVAR)	795.6	604.3	653.5	* NR*	NR*	628.2
Reduction in PLOSS (%)	0	11.7	10.1	0.6	1.3	12.72
Total PLOSS (Mw)	132.8	117.19	119.34	131.99	130.96	115.90

NR* - Not reported.

Table 12. Comparison of real power loss

Parameter	Method EGA [20]	Method EEA [21]	Method CSA [21]	DMEA
PLOSS (MW)	646.2998	650.6027	635.8942	610.1249

5. CONCLUSION

In this work dynamic membrane evolutionary algorithm (DMEA) successfully solved the optimal reactive power problem. Proposed methodology merges the fusion and division rules of P systems with active membranes and with adaptive differential evolution (ADE), particle swarm optimization (PSO) exploration stratagem. In this paper, composition of the dynamic membrane algorithm along with the fusion, division rules are utilized to solve the optimal reactive power problem. In this work, Gaussian probability distribution is initiated to engender the accelerating coefficients of PSO. Proposed dynamic membrane evolutionary algorithm (DMEA) has been tested in standard IEEE 14, 30, 57, 118, and 300 bus test system and simulation results show the projected algorithm reduced the real power loss extensively.

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