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AN OPTIMAL REALLOCATION OF GENERATORS USING A COMBINATORY INDEX AND THE KRILL HERD ALGORITHM IN THE PRESENCE OF SVC

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Abstract : Effective resource utilization is crucial for the electrical business in the current competitive electric environment. It has been discovered that the use of FACTS devices and generators tuned to perfection are highly beneficial in this aspect. This study suggests a combined approach for the best generator tuning in the presence of the Static VAR Compensator (SVC) utilizing the Krill herd (KH) algorithm. The best place for SVC has been determined by combining the L-index and the Vi/Vo index to create a combinatory index (CI), which has been developed and validated. A function with many objectives has been developed to adjust the generators. The outcomes of applying KH to an IEEE 30 bus system for both normal loading and severe system conditions brought on by a line outage in the presence of SVC have been verified against HS data.

***IndexTerms* - Krill herd (KH) algorithm, combinatory index (CI), Static VAR Compensator (SVC), Harmony search algorithm (HS)**

1. INTRODUCTION

SVC is an appropriate solution to address the voltage instability issue since it is a parallel FACTS device. SVC positioning and tuning must be ideal for the equipment to function properly. The installation of the FACTS device has been shown to be straightforward and successful when done using an index-based strategy. To rank the most susceptible buses, the L-index and Vi/Vo index can work quite well together. Using a metaheuristic algorithm, the generators and FACTS devices are optimally tuned. The Krill Herd algorithm was first presented in 2012 and has since shown to be incredibly effective. The best power flow in the presence of SVC has been found in this study using a metaheuristic approach called the Krill herd algorithm. To determine the best position for the SVC device, a Combinatory Index (CI) made up of Vi/Vo and L-index has been developed. For a function with many objectives, the best possible generator tuning has been completed. Diminishing voltage variation, cutting fuel expenses, and lowering transmission line loss are among the several goals. During the optimization process, actual and reactive power generation levels as well as bus voltage limitations are taken into consideration. A comparison was made between the OPF findings and the HS when the Krill-herd method was included. The efficacy of the suggested approach has been demonstrated by a comparison of the optimal tuning outcomes with and without SVC.

2. Index Proposal for Combinatory

With the L-index and the Vi/Vo index from equation (1), a combinatory index is created.

$$\mathbf{Z_1 \times I_1 + Z_2 \times I_2 = CI} \text{ -------------------------- (1)}$$

Z1 and Z2 are the weighting elements in this case. Z1 and Z2 have values of 0.5 and 0.5, respectively. Equation (2) provides the L-Index, which is denoted as I_1.

$$\mathbf{I1} = \left[\mathbf{1} - \sum_{\mathbf{i=1}}^{\mathbf{g}} \mathbf{Fji} \frac{\mathbf{Vi}}{\mathbf{Vj}}\right] \text{ ----------------------------(2)}$$

The value of L-index I1 ranges from 0 to 1. The system's stability is increased when the index value is lower.Load participation factor is represented by Fji, one of the F-matrix entries. For a node admittance matrix, the F-matrix is the partial inverse sub-array. Complex components are symbolized by Fji. At bus I, the voltage magnitude is represented by Vi, while at bus j, it is represented by Vj. Equation (3), where Vi is the reference voltage and Vo is the output voltage, yields the Vi/Vo index, or index I2.

$$\mathbf{I_2 = 1 - V_i/V_o} \text{ ---------------------------------------(3)}$$

3. Problem Formulation:

For the best generator tuning, a multi-objective function that takes into account fuel cost, real power loss, and voltage variation is employed.

$$\mathbf{Min\ F = Min\ (w1 * F1 + w2 * F2 + w3 * F_3)} \text{ ---------------------(4)}$$

Where, F1 is the Fuel cost given by

$$\boldsymbol{F1 = \min\left(\sum_{i=1}^{ng}\left(a_i + b_i P_{Gi} + C_i P_{Gi}^2\right)\right)} \text{ -- -----------(5)}$$

The number of generators in the power system is represented by Ng, and the fuel cost coefficients are a, b, and c. Table 1 lists the values of the coefficients for a number of different generators.

Table 1: Fuel Cost Calculation Values for a, b, and c

G.B.N	a (p.u.)	b (p.u.)	C (p.u.)
1	0.005	2.45	105
2	0.005	3.51	44.1
5	0.005	3.89	40.6
8	0.005	3.25	0
11	0.005	3	0
13	0.005	2.45	105

The true power loss is F2.

$$\mathbf{F2=}\boldsymbol{min}\left(\sum_{i=1}^{ntl}\mathbf{real}\left(S_{jk}^{i} + S_{kj}^{i}\right)\right) \text{ ---------------------(6)}$$

In this case, there are ntl transmission lines and Sjk is the total complex power flowing from bus j to bus k in line I. F3 is the variance in voltage.

$$\mathbf{F3=min\ (VD)=}\boldsymbol{min}\left(\sum_{k=1}^{Nbus}\left(V_K - S_k^{ref}\right)^2\right) \text{ -------------------(7)}$$

The reference value of the voltage magnitude at the bus is V_k^{ref}, while the actual voltage magnitude at bus k is V_k.

Power Balance Constraint

$$\sum_{i=1}^{N} P_{Gi} = \sum_{i=1}^{N} P_{Di} + P_L \text{ ----------------------(8)}$$

Where N is the number of bus and i = 1, 2, 3,..., N. PL represents the system's active power loss.

Voltage balance constrain

$$V_{Gi}^{min} \leq VG_i \leq V_{Gi}^{max} \text{ -------------------------------(9)}$$

Where Gi=1, 2, 3, ...ng and ng = number of Generator buses.

Generation limit real power

$$P_{Gi}^{min} \leq PG_i \leq P_{Gi}^{max} \text{ -------------------------(10)}$$

Where PGi is the active power generated at bus i and PDi is the power demand at bus i, where Gi=1, 2, 3,...ng. Between 0.9 and 1.1 pu are the voltage limitations of the generator buses.

4. Presented Techniques

Figure 1 below lists the steps needed to minimize the objective function using SVC

5. Results and Discussion

The IEEE 30 bus system depicted in Fig. 2 has been used to test the suggested methods. The suggested approach was first examined under typical conditions. The suggested approach has subsequently been tested under unfavorable circumstances by taking into account a line outage scenario. Q_{SVC} = 0.06789 p.u. and B = 0.06789 p.u. are the SVC parameters that are employed. Every bus has its CI value determined. A maximum confidence interval (CI) of 0.10495 p.u. is noted for Bus No. 30. Bus 30 is therefore the system's weakest bus. Various combinations of NR and NK have been employed. The study's chosen formula, NR = 20 = NK, is seen to provide the best and lowest values for the objective function.

5.1 OPF for Normal Condition

After experimenting with various weight combinations for the goal function, the values of the objective function were noted and recorded in Table 2. The results show that w1 = 0.7, w2 = 0.15, and w3 = 0.15 provide the lowest value of the goal function and has been selected as a result for the Examine. OPF boosts the voltage at the buses when SVC is present. Table 3 compares real power production costs for KH-OPF without SVC, HS-OPF without SVC, KH-OPF with SVC, and HS-OPF with SVC, as well as real and reactive power loss, voltage variation, and system-wide real power generation for individual generators. When compared to HS, it is shown that krill herd is far more appropriate for the selected multi-objective optimization problem. Moreover, OPF is found to be significantly more effective when SVC is present than when it is not. Consequently, the apparatus demonstrates exceptional efficacy in optimizing the generators. The Table 4 presents a comparison between the single-objective and multi-objective function performances. The enhancement of several power system characteristics is shown to be better suited for a multi-objective function.

Figure 1: steps needed for multi objective function using KH

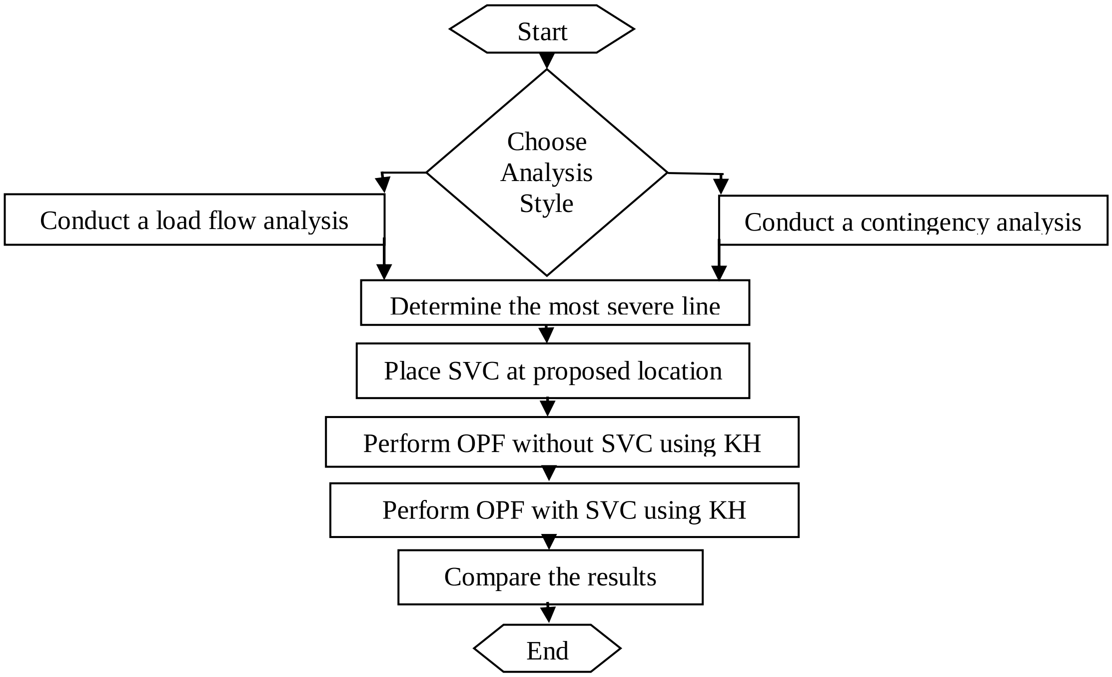

Table 2: Indispensable answers for the Cost, Losses, and Voltage Deviation goals

solution number	weight			
	w1	w2	w3	f1
1	0.7	0.15	0.15	209.7
2	0.55	0.3	0.15	420.4
3	0.4	0.45	0.15	618.5
4	0.25	0.6	0.15	846.4
5	0.3	0.4	0.3	550

Table 3: Comparing the OPF solution utilizing Krill-OPF for a 30-bus system with and without SVC

S.No	Parameter		Krill-OPF without SVC	HS-OPF without SVC	Krill-OPF with SVC	HS-OPF with SVC
1	Real power generation (MW)	PG1	122	135.5568	119.62	154.2099
		PG2	50	32.6893	50	50
		PG5	26.47	29.415	32.7	22.6325
		PG8	40.22	42.8081	37.45	43.3676
		PG11	42	40.5583	39	10.6258
		PG13	10	10	10	10
2	Total real power generation (MW)		290.69	291.0275	288.8	290.8358
3	Total real power loss (MW)		6.618	7.6274	5.42	7.4357
4	Total reactive power loss (MVAR)		19.16	19.38	8.632	12.97
5	Voltage Deviation (p.u.)		1.8355	1.9507	0.2852	0.2898
6	Total real power generation cost ($/h)		1355.33	1360.7	1258.37	1277.8

Figure 2: Example IEEE 30 bus setup.

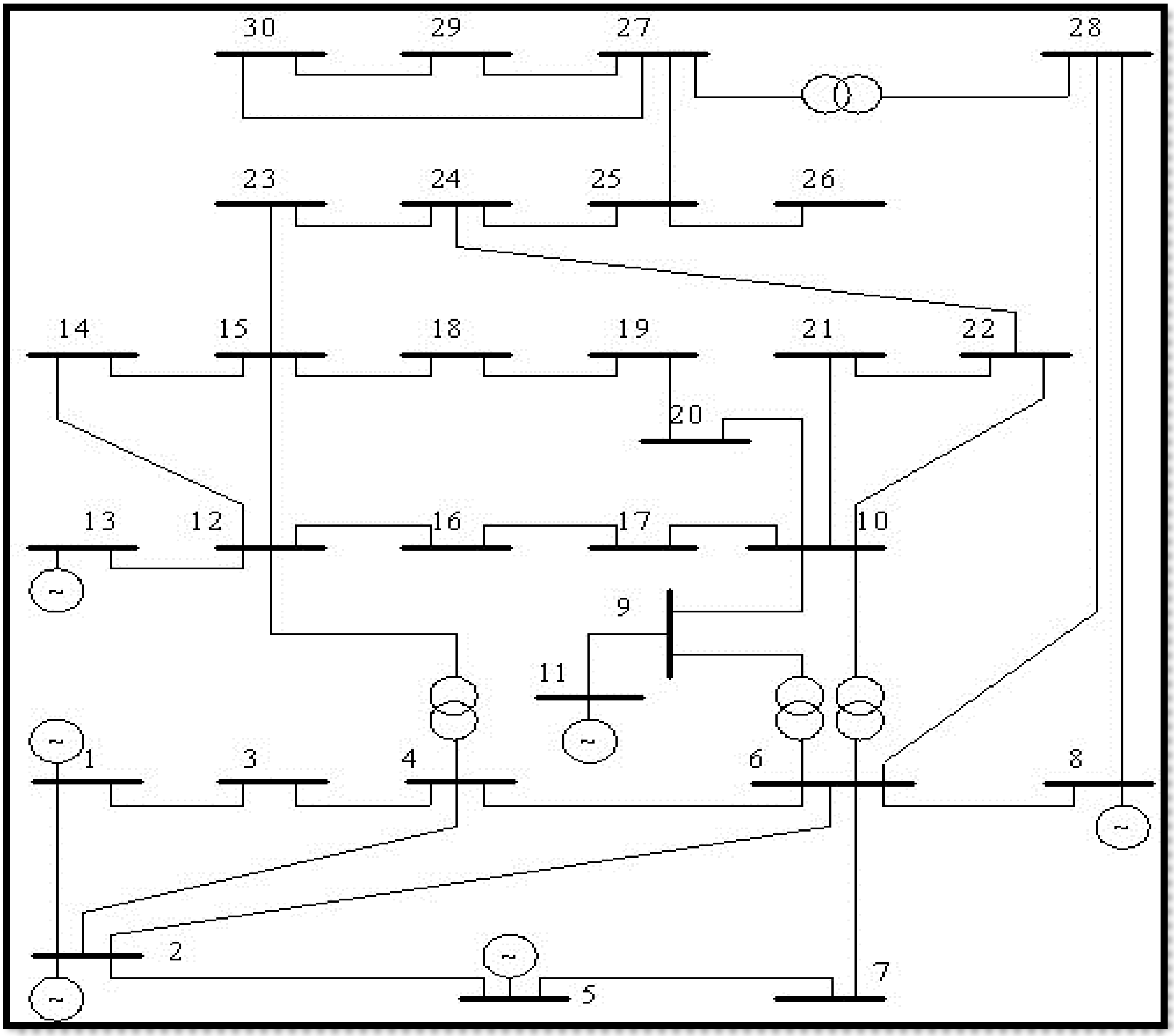

Table 4: Comparing several goals with various goal functions using the Krill Algorithm without SVC.

Variables	OF1	OF2	OF3	OF4
PG1(MW)	184.76	147.4329	154.81	122
PG2(MW)	50	50	29.25	50
PG5(MW)	17.36347	24.44	44.66	26.47
PG8(MW)	12.86	22.79	23.78	40.22
PG11(MW)	14.5	37.67	29.03	42
PG13(MW)	10	10	10	10
Total real power generation (MW)	289.4	292.34	291.5443	290.69
Total real power generation cost($/h)	1407	1360	1380.9	1365.33
Active power Loss (MW)	6	8.9451	8.145	6.618
Voltage deviation (p.u.)	2.5156	2.1545	1.8125	1.8355
Objective function	6 (MW)	1360($/h)	1.8125(p.u.)	209
OF- Objective Function OF1 – only losses OF2- only cost OF3- only voltage deviation OF4 – multi objective functio				

5.2 OPF for Contingency Condition

The IEEE 30 bus system's highest stress is caused by the loss of lines 27–28, as evidenced by the maximum CI value of 0.3998 p.u. in Table??, according to the results of the contingency analysis. It is also noted that bus number 30 is the least reliable bus for the contingencies mentioned above. The device has been installed at a number of different sites to see if the bus identified by CI is indeed the ideal position for the installation of SVC. The findings are shown in Table 6. Placing SVC at the site specified by CI is shown to decrease actual and reactive power loss to the highest degree possible. Therefore, for the study, n − 1 contingency for lines 27–28 and SVC at bus 30 has been taken into consideration. Table 7 presents a comparison of the values of several parameters with SVC location and size, both with and without contingency. It has been noted that when the SVC is sized and placed optimally, the CI value following OPF is lowered to the greatest possible degree. Table 8 displays the system parameters for the single objective and multiobjective function. It is found that a multiobjective function works better to accommodate the different power system parameter features. In Table 9, several power system characteristics for OPF without and with SVC have been examined with and without contingency conditions. It is found that the best option under both regular and emergency conditions is the OPF with SVC. When it comes to the multi-objective function, KH performs better than HS. KH appears to provide a lower value (193.923 p.u.) than HS, which is 199.7049 p.u. The voltage profile significantly improves when KH-OPF SVC is included.

Table 5: Values of Lj, Vi/V0, and CSI during a few line outages of the IEEE 30 Bus Test System

S.NO	Line outage FB-TB	Bus no with max. (Lj)	Lj Value (p.u.	Bus no. with max. (1-Vi/V0)	(1-Vi/V0) (p.u.)	Bus no with max (CI)	CI (p.u.)
1	2 to 5	30	0.1209	30	0.2483	30	0.1766
2	27 to 28	30	0.4522	30	0.3474	30	0.3998
3	27 to 29	29	0.1613	29	0.1761	29	0.1687
4	27 to 30	30	0.1793	30	0.189	30	0.1841
5	29 to 30	30	0.1163	30	0.142	30	0.1291
6	8 to 28	30	0.0891	30	0.1223	30	0.1057
7	6 to 28	30	0.1298	30	0.1583	30	0.1440

Table 6: Comparison of the actual and reactive power losses beneath the 36th line (27–28) with the SVC placed in various places Continuity

S.NO	SVC placement Bus no.	Real power losses (MW)	Reactive power losses(MVAR)
1	30	6.119	7.960
2	29	7.431	8.806
3	27	6.501	9.233
4	25	7.046	11.781

Table 7: Comparing the outcomes at lines (27–28) with and without a contingency

S.NO	Parameter	Values in different system state			
		Without contingency	With Contingency At 27-28	With optimal placement of SVC	With optimal sizing of SVC using Krill Algorithm
1	Active Power Loss(MW)	10.78	15.36	10.64	6.596068
2	Reactive Power Loss(MVAR)	29.98	46.5	22.69	6.6361
3	Lj of Severe bus (p.u.)	0.0895	0.4522	0.0721	0.058468
4	(1-Vi/V0) of Severe bus (p.u.)	0.1204	0.3474	0.0496	0.030961
5	CI of Severe bus (p.u.)	0.10495	0.3998	0.06085	0.043747
6	Voltage Deviation (p.u.)	2.3176	4.0516	0.4252	0.29268
7	Overall Lj (p.u.)	1.2089	3.1974	0.6179	0.500657
8	Overall (1-Vi/V0) (p.u.)	1.8984	3.5476	0.3801	0.280652
9	Overall CI (p.u.)	1.55365	3.3725	0.499	0.390655

6. Conclusion

For the various power system components to be used effectively, optimal power flow is a necessary prerequisite. In this work, an optimal power flow approach using SVC is developed to address power systems' voltage instability problems and minimize losses. To find the SVC's position, a Combinatory Index has been developed.

Table 8: Comparing various objectives with various objective functions with the use of the Krill Algorithm with SVC (SVC is situated at Bus No. 30).

S.NO	Variables	OF1	OF2	OF3	OF4
1	PG1(MW)	99.064	103.748	108.856	133.935

2	PG2(MW)	50.0	50	50	50
3	PG5(MW)	43.713	29.6528	37.461	26.79
4	PG8(MW)	40.988	47.098	43.029	34.4
5	PG11(MW)	44.354	48.234	39.287	34.85
6	PG13(MW)	10	10	10	10
7	Total real power generation (MW) Total real power generation cost($/hr)	288.119 1263.59	288.7328 1255.94	288.633 1261.07	289.975 1261.7
8	Active power Loss (MW)	4.7213	5.3343	5.2353	6.596
9	Voltage deviation (p.u.)	0.29206	0.2920	0.29215	0.2926
10	Objective function value	4.7213(MW)	1255.9($/hr)	0.29215(p.u.)	193.923
*OF- Objective Function OF1 – only losses OF2- only cost OF3- only voltage deviation OF4 – multi objective function					

Table 9: Comparing actual power losses, expenses, and voltage deviations during line outages and regular operations with an SVC installed at bus number 30

Condition	Parameters	KH OPF without SVC	HS OPF without SVC	KH OPF with SVC	HS OPF with SVC
Without Contingency	SVC Rating (p.u.)	–	-	0.06789	0.0675
	Total Real power generation (MW)	290	291.0275	288.8	290.8358
	Real power losses (MW)	6.61	7.6274	5.42	7.4357
	Total generation cost ($/hr)	1355.3	1360.7	1258.3	1277.8
	Voltage Deviation (p.u.)	1.835553	1.9507	0.285292	0.2898
27 to 28 Line outage	SVC Rating (p.u.)	–	-	0.087	0.1529
	Total Real power generation (MW)	293.17	294.9423	289.97	291.4372
	Real power losses (MW)	9.79	11.5423	6.596	8.0372
	Total generation cost ($/hr)	1374.06	1275.7	1261.74	1262.3
	Voltage Deviation (p.u.)	3.291027	3.5378	0.29268	0.3835

To ensure that the index provides the best location for the FACTS device, the findings produced by CI have been validated. A reduction in voltage variation, fuel expense, and transmission line loss is one of the several objectives that have been taken into consideration. For the multi-objective function under consideration, the generators have been optimized using the Krill Herd method. The results show that SVC is highly effective at enhancing the system's voltage profile. The voltage profile is further enhanced by the device's optimal generator reallocation and Krill Herd algorithm adjustment. When optimum power flow is achieved in the presence of SVC, the combinatory index shows an increase in voltage stability. The results demonstrate that, for the selected problem, KH produces better outcomes than HS. It has been discovered that OPF in the presence of SVC is the best way to increase power system performance, as seen by the rise in power system parameter values.

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