Multiple Employed Artificial Bees Colony Algorithm for Allocating Reactive Power Losses in Deregulated Power System

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***Abstract*—**The extensive use of heuristic technique for solving problem given in various field, not the least in power system analysis, has provided a source of inspiration in the determination of reactive power losses that occur along transmission the reactive power from source to consumer in deregulated power system. Based on the original idea of honeybees perform foraging activity from their colony to food source that available in their confines, it has been adopted as proposed in this paper to solve the allocation of reactive power losses to generators in the system by optimization approach. However for allocating the reactive power losses in deregulated power system purpose, multiple numbers of employed bees has been used in performing the Artificial Bees Colony algorithm. The results showed that performance and quality of the experiment is better compared to original ABC algorithm. Meanwhile, a comparative experiment is also performed on conventional method to observe the contribution of generators to power losses that occurs in the system with both methods. IEEE 30-bus Reliability Test System was chosen as a test system in this study.

***Keywords*—**Deregulated power system, allocation, reactive power losses, artificial bees colony algorithm, power tracing.

I. INTRODUCTION

SEVERAL key components in power system such as generators, load and transmission are interconnected with each other regardless the structure of the power system is in vertically integrated or deregulated structure. Some countries over the world have introduced the concept of liberalism to the several industries i.e the electricity supply industry; this is for making electricity market in an open access [1]. Thus any capable utilities can join and provide the best service to consumers in competition spirit. In addition the customers will get the lower price of service with the best service given and not burden to them.

The effect of liberalization on the electricity industries is that, traditional vertically integrated in power system has changed to the deregulated structure. Therefore some practices adopted in vertically integrated such as the transmission usage and loss pricing to the consumer were not allowed to use anymore. In deregulated environment, all the network participant will satisfy if transmission usage and losses cost is charged based on their contribution. Hence, the question of how to determine these two costs must be clear answered. This point does not arise in vertically integrated because the cost has been included in the overall operating system and charged to the consumers. Method of determining the rate of the participants use the transmission line is based on their contribution is called power flow tracing.

In the deregulated power system, although real power is the main commodity trading but the reactive power is necessary for this real power transportation and the more important is for the stability of the system so that the system is always in a reliable condition. Thus the efficient management reactive power supplied by generation side is a very important [2]. So the tool is needed to determine each cost should be borne by the network participants either involving providing and delivering reactive power or loss cost in fair, transparent and non-discriminate form. Various methods are available for allocating reactive power usage charges to consumer either MW-mile, contract path method or power tracing technique [3]. Among these three methods, power tracing is identified have proven that the transmission usage and loss allocation will be based on the actual contribution of the generator or load respectively with considering power system constraint.

The first effort made in tracing power and proposed by Bialek found in [4-6]. By using the principle of proportional sharing power flow tracing can be performed either using downstream-looking or upstream-looking algorithm. Power flow tracing process is performed in the method by making the network in lossless. There are three ways proposed to make the network lossless i.e. average, gross and net flows line. Through the proposed technique, the line losses can be allocated either to the generator or load depends on the upstream-looking or downstream-looking algorithm preferred.

In [7] power tracing is performed by allocating the generator's contribution to the bus voltages and line currents. Yield of these two tracing results are then multiplied both of them to get the next generation's contribution to the line usage and losses as complex power then their real and reactive power can be determined. The disadvantage of this technique is that there is a negative value in the generator contribution to the

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line; this means that it seems to draw the power from line to generator line. Since recently some researchers to turn their attention to use Artificial Intelligence based approach in the performing of this power tracing power. In [8] Genetic Algorithm and [9, 10] Evolutionary Programming were used to allocate real and reactive power loss and load flow to the generator in their power tracing technique respectively. Furthermore, Hybrid Ant Colony is proposed to do a same task for allocating the reactive power losses in the system based on optimization approach [11].

In addition, the ABC algorithm that also belongs to the swarm intelligence like GA and EP has been used actively to solve the problems that arise in engineering field. ABC algorithm was originally invented and proposed by Karaboga to solve numerical problems [12, 13]. While ABC algorithm is used with modification on mutation process done by onlooker for solving the constraint and unconstraint problem proposed in [14-15] with better results. In [16] the allocation of FACTS devices in deregulated electricity market has been solved successfully by applying the ABC algorithm. ABC Algorithm without any modification of original ABC algorithm has been used to allocate the real and reactive power losses to the generator in the power tracing technique in [17, 18].

In this paper proposes a new method for allocating the reactive power losses in the deregulated power system by adding the number of employed bees in their foraging activity concurrently, which termed as Multiple Employed Artificial Bee Colony Algorithm (ME-ABC Algorithm).

II. Reactive Power Flow

Along the transportation of real and reactive power in the transmission line, the power losses will be occurred. To trace the real power losses contributed by generator or load is relatively straightforward because the sending magnitude power at a node is always greater than receiving magnitude power at another node for each line. However the direction for the reactive power flow is varies depending on line charging influence. Therefore it is needed to determinate the direction of reactive power flow on particular line. Thus direction of the reactive power flow at particular line should be identified first prior to perform the reactive power tracing. By doing this, a particular line can be determined whether it acts as a sink or source to the system.

A. Reactive power flow pattern

In general, for a particular line it can be one of the four types of line as shown in Fig. 1.

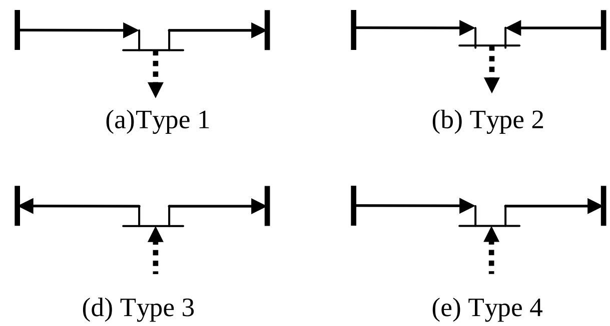

Fig. 2 Reactive power flow pattern

From the sketch diagram as shown in Fig. 1, the dotted line in the middle of bus *i* to bus *j* is implying that there is an injection or extraction reactive power from the system. Type 1 as sketched in Fig. 1(a) is the actual reactive power loss on the line. This is due to the magnitude sending reactive power *Qi* is greater than receiving power *Qj*. For type 2, although the direction of dotted line is similar to type 1 but here it is considered as the reactive power extraction from the system or grouped as a load for the system. While type 3 and 4 acts as reactive power source to the system which is implying amount of reactive power are injected to the middle of lines.

Instead of line flow pattern as briefed in the above statement to illustrate the sources or sink of reactive, the other components such as shunt elements (capacitor bank, FACTS devices), capacitive load and synchronous generators are can be one of a reactive power sources. However synchronous generators and load can be as a reactive power source or sink depending on the behavior of them i.e. it consume or produce reactive power to the system.

After identifying all the elements either they are reactive power sources or sink to the system, thus reactive power tracing can be performed for the purpose to allocate the reactive power loss at line to the generator.

B. Reactive power line loss and load flow allocation

Prior to apply the ABC algorithm into reactive power tracing, the mathematical equation of balanced power flow in the system must be cleared. For the stable system, total reactive power source is equal to total reactive power consume and losses as express in Eq. 1.

$$\sum_{i=1}^{nsc} Q^{sci} = \sum_{n=1}^{nline} Q_{loss\_n} + \sum_{k=1}^{nload} Q_{Dk} \quad (1)$$

Where

Q^{sci} = reactive power from source i

Q_{loss_n} = reactive power loss at line n

Q_{Dk} = reactive power demand at bus k

As explained in subsection 2.1, reactive power sources may come either from synchronous generator, inductive load, and line as well as shunt element. While reactive power load for the system may be from synchronous generator, line or also capacitive load.

For performing power tracing purpose, *x* is representing percentage or fraction of generator *n* to line loss/sink and *y* is representing of generator's fraction to load as expressed in Eq. 2 and 3 respectively.

$$Q_{loss\_n} = \sum_{i=1}^{nsc} x^{sci} \left[Q_{loss\_n} \right] \tag{2}$$

where

Q_{loss_n} = reactive power loss at line n

x^{sci} = fraction of source i to reactive power loss at line n

$$Q_{Dk} = \sum_{i=1}^{nsc} y^{sci} \left[Q_{Dk} \right] \tag{3}$$

Q_{Dk} = reactive power demand at load k

y^{sci} = fraction of source i to reactive power demand at load k

III. MULTIPLE EMPLOYED ARTIFICIAL BEE ALGORITHM

Artificial Bee Colony algorithm is a one of the stochastic swarm optimization using the meta-heuristic approach. It was applied for solving the combinatorial optimization problem. The uniqueness of bee colony in food foraging behavior is that, they uses a specific communication system to find the optimum food. It has given an inspiration to researchers in their fields to solve a problem by using the optimization approach.

In the original ABC algorithm, the nature colony of bee that assigned for food searching is divided to three groups: employed bees, onlookers and scouts. On these three groups, they will search the food by different approach among them. Employed bees will go to the food source and determine the neighborhood source and produce the new solution. They going back to the hive and perform the waggle dance and the onlookers will watch it. Then the onlooker will goes to the food source but now the selection of food position is depending on the dances information. After determine the food position, she will produce the new food source by using the neighborhood search process. The abandoned food source that it does not improve by these two employed and onlooker bees, the food source will replace with new randomly food sources discovered by scouts. Each time after all artificial bees (employed and onlooker bees) complete their job; the best food source will be registered. However, if the number of employed bees commissioned to conduct exploration process is more than one, the probability of finding more food sources and higher quality is automatically increased and also indirectly help shorten the process of foraging activity from the nest to a food source at one time.

Prior to that to employ the Multiple Employed ABC algorithm, some parameter controls are required to be set. There are number of colony size, number of employed bees for one short exploration, number of maximum cycle (MCN) and limit of abandoned solution for scout to search new randomly produced solution.

A. Step of Multiple Employed ABC Algorithm Implementation

- Initialize the solutions (food sources)
- Evaluate the population (the nectar amount)
- Produced new solution by using neighborhood search of several employed bees.
- Apply the greedy selection (choose the best one of solution)
- Calculate the probability values associated with the solution.
- Produce new solution for onlookers that depending on the probability associated with the solution.
- Re-apply the greedy solution (choose the best one the solution).
- Determine the abandoned solution for scout, if exists, replace with new randomly produced solution.
- Memorize the best solution achieved so far.
- Cycle=cycle +1 (until achieve objective function).

A. Application of Multiple Employed Artificial Bees Algorithm

From Eq. 2 and 3, Modified Employed ABC algorithm is applied in the optimization process by searching the optimum value of *x* and *y* fraction with the minimum value of objective function (the best solution). The explanation of the global optimization process for the problem given is expressed in Eq. 4.

$$\min \; f(\vec{x}, \vec{y}) \tag{4}$$

$$\vec{x}, \vec{y} = (x_1, x_2, ., x_i, ., x_{n-1}, x_n, y_1, y_2, ., y_i, ., y_{n-1}, y_n) \in R^n$$

which constrained by the inequalities lower and upper bound $lb \le x_i, y_i \le ub$.

The optimization process begins with setting the number of food source in this ME-ABC process in which each food source represents the several number of flower patches. For reactive power tracing task, food sources are representing the percentage of line losses and load contributed by generators in the system.. Several employed bees will flying to each food source concurrently then evaluates the quantity of nectar in the same time. Prior to that, the parameters row vector of each food sources are initialized by using a uniform random number with constraint from 0 to 1.

The notation of *x* and *y* fraction that contributed by particular generator in a food source form as proposed by original ABC algorithm for optimization purpose is showing in matrix below in Eq. 5.

$$S = \begin{bmatrix} x_1^{sc1} \dots x_n^{sc1} \; y_1^{sc1} \dots y_n^{sc1} \; x_1^{scn} \dots x_n^{scn} \; y_1^{scn} \dots y_n^{scn} \\ \downarrow \qquad \qquad \downarrow \qquad \qquad \downarrow \\ x_k^{sc1} \dots x_n^{sc1} \; y_k^{sc1} \dots y_k^{sc1} \; x_k^{scn} \dots x_n^{scn} \; y_k^{scn} \dots y_n^{scn} \end{bmatrix} \tag{5}$$

The x and *y* random values are then multiplied to the actual each line losses and load demands respectively which represent a solution (mismatch) of a problem. From these initialization values in each solution, the mismatch power will be calculated as in Eq. 6.

$$\min(H) = \sum_{n \notin nline} \Delta Q_{loss\_n}^{sci} + \sum_{k \notin nload} \Delta Q_{Dk}^{sci} + \sum_{m \notin nsc} \Delta Q^{scm} \tag{6}$$

where

$$\Delta Q_{loss\_n}^{sci} = Q_{loss\_n}^{sci(pf)} - Q_{loss\_n}^{sci(abc)}$$

$$\Delta Q_{Dk}^{sci} = Q_{Dk}^{sci(pf)} - Q_{Dk}^{sci(abc)}$$

$$\Delta Q^{scm} = Q^{scm(pf)} - \left(\sum Q_{loss\_n}^{abc} + \sum Q_{Dk}^{abc} \right)$$

Note that *pf* is stand for power flow solution, hence $Q^{scm(pf)}$ and $Loss_n^{pf}$ are results obtained from power flow solution.

This mismatch power will be transform to fitness scheme using the equation 7.

$$f_i = \frac{1}{1+H} \tag{7}$$

This fitness illustrates the quality of each food source (solution) in the ABC algorithm. Among the n^{th} solution, the best quality will be registered in a memory as a best solution found. The searching process for finding the best fitness value will continue via multiple employed bee foraging method with neighborhood search by using Eq. 8.

$$v_{ij} = x_{ij} + rand(x_{ij} - x_{jk})(rand - 0.5) * 2 \tag{8}$$

The fitness value will be evaluated for each new *x* and *y* representing generator contribution that has been mutated for each solution. The new *x* and *y* that was mutated and having the best fitness value will be as a new reference in memory. The optimization process will continue with onlooker bees in foraging process in which the neighborhood search is depending on the probability of the previous result of fitness value in employed bees by using Eq. 9. The new variable *x* and *y* after mutation process with neighborhood search will be recorded if it fitness is better.

$$\rho_i = 0.9 \left(\frac{f_i}{\max(f_i)} \right) + 0.1 \tag{9}$$

To use the ABC algorithm, the number of trial to scout bee performs new exploration process is to be set for the purpose if employed and onlooker bees showed no improvement after several unsuccessful attempts are made. The number of trial cannot be too large and too small. The trial number that are too large will cause discovery of new solution process cannot be done even if there is no progress on the findings result in the optimization process to converge. While the number of trial that are too small will lead to exploration for new discoveries too quickly before the mutation process with a better result can be achieved. Proses optimization process will continue in iteration form until the solution is converged i.e mismatch power *H* is close to zero.

The whole application of ABC approach in line loss and load allocation is as shown in Fig. 2.

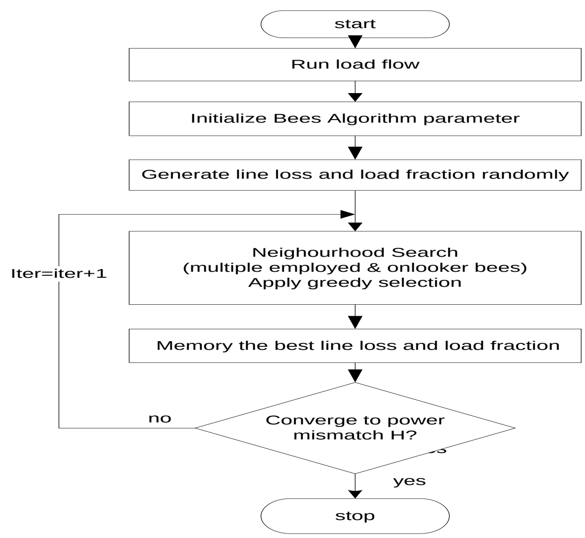

Fig. 2 Flow chart of ABC application in reactive power losses and load flow allocation.

IV. RESULTS AND DISCUSSION

To test the validity of the proposed method, IEEE-30bus Reliable Test System was selected to be tested in order to perform reactive power tracing for allocating the line losses to generators. This test system is suitable for doing the experiment because there is diversity trends of reactive power flow direction on transmission line in which some acts as a source or consumer of reactive power of system. While for some other transmission line, there is a loss of power during power delivering from source to consumer. For this system, there are five synchronous generators as a major source of reactive power, two capacitor banks injected at particular buses and five lines act as a source of reactive power to the system. Generator at bus 1 is acting as a load where it uses reactive power exceeds with its generation.

Test results showed that the number of employed bees that are assigned to make exploration in concurrently can affect the speed of time required for a given problem are solved using an optimization approach; ie reactive power losses allocation. Test was performed by setting the number of employed bee with single employed bee (original ABC) until several employed bee. In this case the number of maximum employed bee is ten. From Fig. 3 can be observed the experiment results show that by same number of iteration (time consuming), the increase number of employed bees is greatly influence the speed of solution to converge.

Fig 3. Trend of convergence speed according to number of employed bees assigned.

The speed of the proposed method compared with the original ABC algorithm as shown in Fig 4. Proven that the graph slop graph has shown that the proposed method converge faster towards the same objective function target. For comparison purpose, it can be observed from Fig. 4 the objective function value with single employed bee is 144 965 while for ten employed bees, its objective value is 5964. Thus the values of the ten employed bees are proposed method in the experiment for allocating reactive power losses.

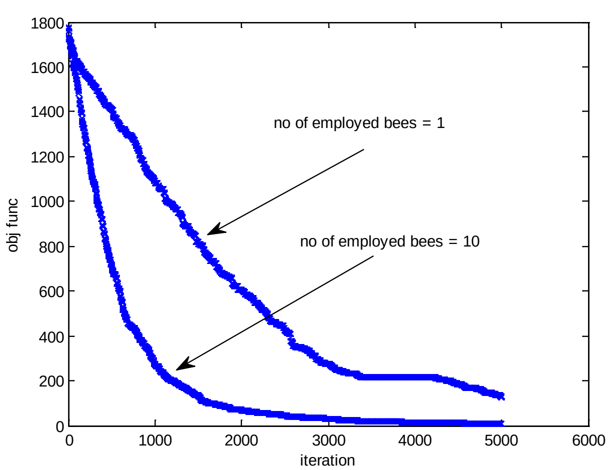

Fig.4 Comparison of convergence speed with different employed bees number

By using the multiple employed bees artificial bees algorithm (ME-ABC algorithm) with ten employed bees it found that the required time is far least compared to original ABC algorithm to converge. ME-ABC only take 650.82 seconds while almost half an hour time required for original ABC to converge with same objective function target i.e. 0.005.

Through this experiment result of the proposed method and Bialek's method for allocating the individual transmission line and load to the individual reactive power source is tabulated in Table 1 and Table 2. Analysis is only focused on synchronous generator contribution to the total power losses of each transmission line. The losses of power here are including the losses of power during transmission and the power consumption for the line that acts as a sink to the system. While for reactive power sources, only the results of synchronous generator are reviewed here, in order to describe the cost of these transmission lost that reflect to these generator utilities should be recovered.

From the graph shown in Fig.5, it is found that from both methods generator at bus 2 is the main contributor for the whole losses of reactive power that occurs on the transmission lines in the system. However result of the proposed method, generator at bus 2 contributes 14.4453 MVar lower than Bialek's method which contributes 18.0981 Mvar. While contribution of generator at bus 5 to system losses by proposed method is quite closed to Bialek's method in which 8.8359 Mvar and 7.0427 Mvar respectively. It is similar to Gen 3 in which contribute 8.88359 Mvar and 7.0427 Mvar respectively. Generator contribution at bus 8 is significant difference between proposed method and Bialek's method, that is 8.8658 Mvar and 1.5215 Mvar respectively. Generator at bus 10 is the least contributor to the system loss obtained by proposed method with 0.899 Mvar and by Bialek's method generator at bus 11 is found as the least contributor.

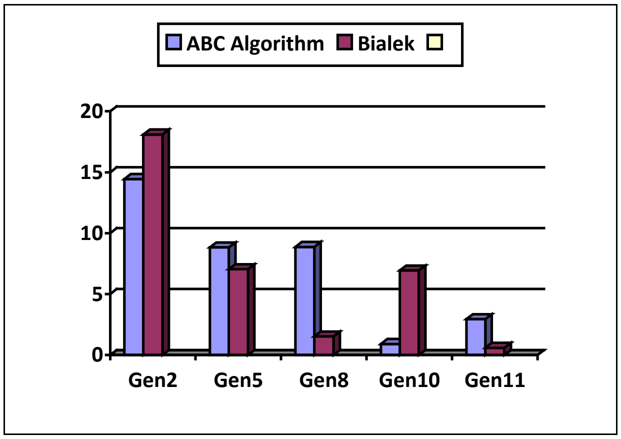

Fig. 5. Generator contribution to total reactive power losses.

Although there are some variation in results generated compared to conventional method, but it still satisfies all set of power system constraints as the total power losses on transmission line and load in a system is equal to the amount of power supply to the system. For the proposed method, the results shown in Table 1, the total reactive power losses is 43.005 MVar and power required by load is 143.227 Mvar. The summation of these two powers is balanced to the reactive power generated to the system in which 186.283 MVar. This indicates that the ME-ABC algorithm has been successfully performed for allocating power losses in transmission lines to system's generator by means reactive power tracing with the fast convergence and required time only 650.82 seconds and converge mismatch power 0.0005 as shown in Fig. 6.

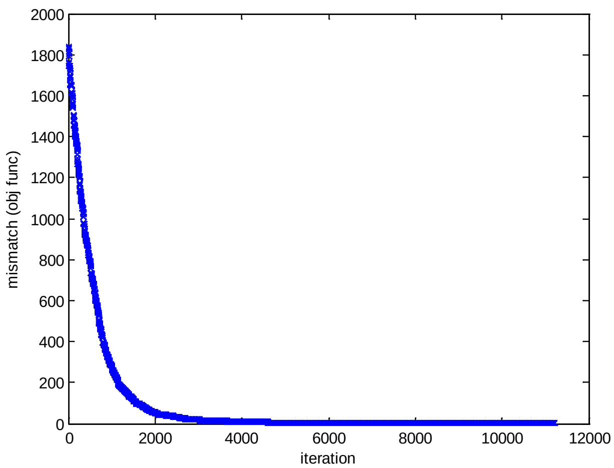

Figure 1. Convergence of objective function with multiple employed bees

V. CONCLUSION

By mimicking the inspiration of real bees perform foraging activity using the iteration process for finding the best food with solution space, it has adapted to the activity of power tracing problems. With only the reactive power information generated by each reactive power sources component and the flow of reactive power source for each line from result of power flow solution, ME-ABC algorithm is able to trace the contribution of reactive power source to the loss of reactive power at each transmission line and also to the power extracted by the load in a system. Based on power balanced equation of a system, results of power flow solution are compared to the results obtained by iteration process performed by ABC algorithm in implementing reactive power tracing process. The difference result of this comparison is used as an objective function in which closet to zero. Although involving iteration process in ME-ABC algorithm for tracing the reactive power losses, the required time is still acceptable and reasonable without the need for any matrix inversion and assumptions such as proportional sharing. In addition, instead allocating the transmission losses to the system's generator, the allocation of load power is concurrently executed.

TABLE 1
REACTIVE POWER LOSSES AND LOAD ALLOCATION VIA ME-EMPLOYED BEES

Line	Generator Bus					C-Bus		Lines behave as reactive source						Total
	2	5	8	10	11	13	24	L 2-4	L5-7	L6-7	L6-8	L8-28	L6-28	
1-2	2.8644	2.3744	2.7230	0.0670	0.2918	0	0.1518	0	0	0	0	0.1032	1.9487	10.5234
3-4	0.8901	0.2581	0	0	0.2001	0	0	0	0	0	0	0	0	1.3446
2-6	0.2197	1.0959	0.3292	0.0758	0.0435	0.0455	0.0324	0.2736	0.0018	0.0034	0.0136	0.0038	0.1251	2.2637
4-6	0	0.0280	0.2120	0.0101	0.2631	0.0199	0.0165	0	0	0	0	0	0.6309	1.1797
6-9	0.9564	0	0	0	0.0140	0	0	0	0	0	0	0	0.6262	1.5938
9-11	0.4302	0	0	0	0.0001	0	0	0	0	0	0	0.0150	0.0162	0.4614
9-10	0.5590	0.0185	0.0632	0.0810	0.0055	0.0009	0.0511	0	0.0089	0.0004	0.0020	0.0005	0.0176	0.8088
4-12	0.0003	3.0043	0.1172	0.4980	0.6894	0.0276	0.2326	0.0043	0	0.0438	0.0621	0.0047	0	4.6830
12-13	0	0	0.0159	0.0126	0.0987	0	0.0002	0	0.0051	0	0	0.0000	0	0.1326
12-14	0.0930	0.0015	0.0019	0.0166	0.0117	0.0000	0.0090	0	0.0023	0.0132	0	0	0.0058	0.1554
12-15	0.0003	0.0077	0.1951	0.0704	0	0	0.0389	0.0127	0.0093	0	0.0002	0.0096	0.0842	0.4283
12-16	0.1105	0	0	0.0003	0	0.0001	0	0	0	0	0	0.0011	0.0006	0.1125
14-15	0.0028	0.0003	0	0.0019	0	0	0	0	0	0	0	0.0000	0.0004	0.0060
16-17	0.0003	0.0001	0.0056	0	0.0002	0	0	0	0.0025	0	0.0038	0.0146	0.0002	0.0272
15-18	0.0008	0	0	0.0037	0.0646	0.0021	0.0002	0	0.0081	0	0	0	0	0.0803
18-19	0.0081	0	0	0.0026	0	0	0	0	0	0	0	0	0	0.0101
19-20	0.0003	0	0.0334	0	0	0	0.0001	0	0	0	0	0	0	0.0338
10-20	0.0318	0.0253	0.0291	0.0122	0	0.0810	0	0	0.0005	0	0	0	0.0007	0.1804
10-17	0.0257	0.0050	0	0	0	0	0	0	0.0069	0	0	0	0	0.0374
10-21	0	0.0185	0.1283	0.0007	0.0558	0.0011	0	0.0030	0.0183	0.0004	0	0.0104	0	0.2372
10-22	0.0015	0.0093	0	0.0001	0.0096	0.0013	0.0000	0	0.0004	0	0	0.0016	0.0831	0.1073
21-22	0.0002	0.0007	0.0004	0	0.0000	0	0	0	0	0	0	0	0	0.0013
15-23	0.0056	0	0.0260	0.0018	0	0.0077	0	0	0	0	0.0004	0.0084	0.0131	0.0631
22-24	0.0008	0.0015	0.0636	0.0002	0.0003	0	0	0	0	0.0002	0	0	0	0.0667
23-24	0	0.0064	0	0.0016	0	0	0	0	0	0	0	0.0045	0	0.0123
24-25	0.0028	0.0013	0.0045	0.0001	0.0001	0	0.0049	0	0	0	0	0	0	0.0136
25-26	0.0198	0	0	0	0	0	0	0	0	0	0	0	0.0489	0.0665
25-27	0.0000	0.0333	0.0075	0.0038	0	0.0000	0.0004	0	0	0	0	0.0004	0.0036	0.0489
28-27	0	0.2206	0.9747	0.0190	0.0005	0	0.0051	0.0120	0.0013	0.0007	0	0.0049	0.0706	1.3094
27-29	0.0121	0	0	0	0.1484	0	0.0017	0	0	0	0	0	0	0.1621
27-30	0.1079	0.0066	0	0.0138	0.0004	0	0.0152	0	0.0109	0.0031	0.0163	0.0054	0.1245	0.3040
29-30	0.0722	0	0	0	0	0	0	0	0	0	0	0	0	0.0631
Total Loss	14.2531	8.8293	8.8658	0.8852	2.7894	0.2531	0.6147	0.3945	0.3203	0.419	0.085	0.1999	4.6306	26.5178
1-3	6.9268	0	0	0	0.1571	0	0	0	0.0012	0	0	0	0	7.0851
2-5	0.3442	1.6540	3.8094	0	0.8776	0.0451	0.0012	0.0527	0.2528	0.2874	0	0	0.8538	8.1782
6-10	0.7577	0.0646	0.1258	0.0057	0.0057	0.0208	0.0703	0.0362	0.0009	0.0695	0.0029	0.0172	0.1009	1.2782
Total Sink	0.1922	0.0066	0	0.0138	0.1488	0	0.0169	0	0.0109	0.0031	0.0163	0.0054	0.1245	16.5372
Total Line	**14.445**	**8.836**	**8.866**	**0.899**	**2.938**	**0.253**	**0.632**	**0.395**	**0.331**	**0.422**	**0.101**	**0.206**	**4.755**	**43.055**
Bus1	6.2543	0.9470	3.2078	0.7912	1.1858	2.3341	0.3897	0.0342	0.4558	0	0.0197	0.4224	0.9760	17.0173
Bus2	1.0558	6.5594	1.5352	2.7968	0.6329	0.0459	0.0406	0.0014	0.0292	0	0	0	0	12.6987
Bus3	0.1215	0.3868	0	0.2078	0.1428	0.0727	0.2278	0	0.0048	0.0101	0.0178	0.0072	0.0001	1.1998
Bus4	0.8496	0.1777	0.4796	0.0067	0.0487	0	0.0279	0.0008	0	0.0025	0.0064	0	0	1.5987
Bus5	3.7423	4.6505	4.4293	0.9209	1.4895	0.6086	1.4405	0.0000	0.4711	0.0211	0.0307	0.3939	0.7931	18.9995
Bus7	1.9119	0.7007	0.0104	0	4.3813	0.3151	0.2814	0	0.0040	0.0013	0.0098	3.2172	0.0655	10.8995
Bus8	4.3831	0.0617	2.3994	12.3480	2.5215	6.2823	0.4018	0.0013	0.0014	0.0007	0.1071	0	1.4916	30.0134
Bus10	1.3754	0.0053	0.0328	0.0203	0.3280	0.0454	0	0.0122	0.0316	0.0023	0	0	0.1467	2.0000
Bus12	4.3855	1.9000	1.0505	0	0.1256	0	0.0314	0.0027	0.0025	0.0006	0.0007	0.0005	0	7.5009
Bus14	0.0324	0.0080	0.6639	0.0757	0.3145	0.0005	0.0471	0.0071	0.0055	0	0	0.0587	0.3867	1.5999
Bus15	0.2408	1.1288	0.0791	0	0.5325	0	0.3841	0	0	0	0	0.0146	0.1213	2.4999
Bus16	0.3806	0.6022	0.6127	0	0.0003	0.0216	0.0001	0	0.0305	0	0.0865	0	0.0653	1.8000
Bus17	2.6672	1.1118	0.0611	0.4552	0.2999	0.1772	0.0270	0.0252	0.2207	0.0030	0.0471	0.0000	0.7036	5.8000
Bus18	0.2161	0.0833	0.2049	0.0390	0.0876	0	0.1296	0.0071	0.0030	0.0054	0	0	0.1236	0.9000
Bus19	0.8094	0.2585	1.7533	0.2585	0.2255	0.0001	0	0.0004	0.0047	0	0	0.0001	0.0890	3.4009
Bus20	0.4397	0	0	0.0541	0	0.0028	0.0385	0.0264	0.0291	0.0065	0.0476	0.0406	0.0148	0.7000
Bus21	3.5358	0.0152	4.7869	0.0422	0.3058	0.1381	0.0438	0.0030	0.0165	0.0674	0.0834	0.0001	2.1618	11.1990
Bus23	0.8930	0.6738	0.0000	0.0000	0	0.0005	0.0105	0	0	0	0	0	0.0220	1.6002
Bus24	0	6.5503	0	0	0.1504	0	0	0	0	0	0	0	0	6.7004
Bus26	0.4535	1.2870	0.3770	0.0210	0.0354	0.1255	0.0000	0	0.0005	0	0	0	0	2.2993
Bus29	0.4061	0	0.1726	0	0.0552	0	0.1257	0	0.0243	0.0559	0	0.0018	0.0583	0.8999
Bus30	0.2226	0.0308	0.1041	0.0629	0.3173	0	0.0207	0.0033	0.0202	0.0004	0	0.0061	1.1109	1.9001
Total Load	34.377	27.139	21.961	18.100	13.181	10.170	3.668	0.125	1.355	0.177	0.457	4.163	8.330	143.227
Total	48.822	35.975	30.826	18.999	16.119	10.424	4.300	0.520	1.687	0.599	0.558	4.369	13.085	186.283

TABLE 2
REACTIVE POWER LOSSES AND LOAD ALLOCATION VIA BIALEK METHOD

Line	Generator Bus					C-Bus		Lines behave as reactive source						Total
	2	5	8	10	11	136	247	L 2-48	L5-79	L6-7	L6-8	L8-28	L6-28	
1-2	10.3214	0.0099	0.0266	0.0657	0	0	0	0	0.0016	0.0054	0.005	0.002	0.0862	10.5238
3-4	0.1718	0.0559	0.1497	0.3693	0	0	0	0.0335	0.009	0.0302	0.0281	0.0115	0.485	1.344
2-6	0	0.1112	0.2976	0.7343	0	0	0	0	0.0179	0.06	0.056	0.0229	0.9645	2.2644
4-6	0	0.0579	0.155	0.3825	0	0	0	0	0.0093	0.0313	0.0291	0.0119	0.5024	1.1794
6-9	0	0	0	1.5937	0	0	0	0	0	0	0	0	0	1.5937
9-11	0	0	0	0.4616	0	0	0	0	0	0	0	0	0	0.4616
9-10	0	0	0	0.8089	0	0	0	0	0	0	0	0	0	0.8089
4-12	0.599	0.1949	0.5217	1.287	0	0	0	0.1168	0.0313	0.1052	0.0981	0.0401	1.6906	4.6847
12-13	0	0	0	0	0.1326	0	0	0	0	0	0	0	0	0.1326
12-14	0.0097	0.0032	0.0085	0.0209	0.0787	0	0	0.0019	0.0005	0.0017	0.0016	0.0007	0.0275	0.1549
12-15	0.0269	0.0088	0.0235	0.0579	0.2176	0	0	0.0053	0.0014	0.0047	0.0044	0.0018	0.076	0.4283
12-16	0.0071	0.0023	0.0062	0.0152	0.0571	0	0	0.0014	0.0004	0.0012	0.0012	0.0005	0.02	0.1126
14-15	0.0003	0.0001	0.0003	0.0007	0.0028	0	0	0.0001	0	0.0001	0.0001	0	0.001	0.0055
16-17	0.0017	0.0006	0.0015	0.0037	0.0138	0	0	0.0003	0.0001	0.0003	0.0003	0.0001	0.0048	0.0272
15-18	0.005	0.0016	0.0044	0.0108	0.0404	0	0	0.001	0.0003	0.0009	0.0008	0.0003	0.0141	0.0796
18-19	0.0006	0.0002	0.0006	0.0014	0.0051	0	0	0.0001	0	0.0001	0.0001	0	0.0018	0.01
19-20	0	0	0	0.008	0	0.0258	0	0	0	0	0	0	0	0.0338
10-20	0	0	0	0.0429	0	0.1375	0	0	0	0	0	0	0	0.1804
10-17	0	0	0	0.0089	0	0.0285	0	0	0	0	0	0	0	0.0374
10-21	0	0	0	0.0563	0	0.1802	0	0	0	0	0	0	0	0.2365
10-22	0	0	0	0.0254	0	0.0813	0	0	0	0	0	0	0	0.1067
21-22	0	0	0	0.0003	0	0.001	0	0	0	0	0	0	0	0.0013
15-23	0.004	0.0013	0.0035	0.0086	0.0322	0	0	0.0008	0.0002	0.0007	0.0007	0.0003	0.0112	0.0635
22-24	0	0	0	0.0159	0	0.0508	0	0	0	0	0	0	0	0.0667
23-24	0.0008	0.0003	0.0007	0.0017	0.0062	0	0	0.0002	0	0.0001	0.0001	0.0001	0.0022	0.0124
24-25	0.0001	0	0.0001	0.0013	0.0011	0.0034	0.0071	0	0	0	0	0	0.0004	0.0135
25-26	0.0004	0.0001	0.0004	0.0044	0.0035	0.0111	0.0231	0.0001	0	0.0001	0.0001	0.008	0.0151	0.0664
25-27	0	0	0	0	0	0	0	0	0	0	0	0.0179	0.0311	0.049
28-27	0	0	0	0	0	0	0	0	0	0	0	0.4789	0.8306	1.3095
27-29	0	0	0	0	0	0	0	0	0	0	0	0.0593	0.1029	0.1622
27-30	0	0	0	0	0	0	0	0	0	0	0	0.1111	0.1928	0.3039
29-30	0	0	0	0	0	0	0	0	0	0	0	0.0231	0.04	0.0631
Total Loss	11.1488	0.4483	1.2003	5.9873	0.5911	0.5196	0.0302	0.1615	0.0261	0.2420	0.2352	0.7905	5.1002	26.5175
1-3	5.2786	0.0863	0.2311	0.57	0	0	0	0.0488	0.0139	0.0466	0.0434	0.0178	0.7488	7.0853
2-5	1.6707	6.4761	0.0043	0.0106	0	0	0	0	0.0003	0.0009	0.0008	0.0003	0.014	8.178
6-10	0	0.032	0.0858	0.3605	0	0.4768	0	0	0.0051	0.0173	0.0161	0.0066	0.278	1.2782
Total Sink	6.9493	6.5944	0.3212	0.9411	0	0.4768	0	0.0488	0.0652	0.0648	0.0508	0.0247	1.0408	16.5415
Total Line	**18.0981**	**7.0427**	**1.5215**	**6.9284**	**0.5911**	**0.9964**	**0.0302**	**0.2103**	**0.0913**	**0.3068**	**0.286**	**0.8152**	**6.141**	**43.059**
Bus1	16.6934	0.0161	0.043	0.1062	0	0	0	0	0.0026	0.0087	0.0081	0.0033	0.1395	17.0209
Bus2	12.4556	0.012	0.0321	0.0792	0	0	0	0	0.0019	0.0065	0.006	0.0025	0.1041	12.6999
Bus3	0.1534	0.0499	0.1336	0.3297	0	0	0	0.0299	0.008	0.0269	0.0251	0.0103	0.4331	1.1999
Bus4	0.2046	0.0666	0.1782	0.4396	0	0	0	0.0399	0.0107	0.0359	0.0335	0.0137	0.5774	1.6001
Bus5	0	19	0	0	0	0	0	0	0	0	0	0	0	19
Bus7	0	9.3914	0	0	0	0	0	0	1.5086	0	0	0	0	10.9
Bus8	0	0	27.8584	0	0	0	0	0	0	0	0	2.1415	0	29.9999
Bus10	0	0	0	0.4759	0	1.5241	0	0	0	0	0	0	0	2
Bus12	0.4717	0.1534	0.4108	1.0135	3.8111	0	0	0.092	0.0246	0.0828	0.0772	0.0316	1.3313	7.5
Bus14	0.1006	0.0327	0.0876	0.2162	0.813	0	0	0.0196	0.0053	0.0177	0.0165	0.0067	0.284	1.5999
Bus15	0.1572	0.0511	0.1369	0.3378	1.2704	0	0	0.0307	0.0082	0.0276	0.0257	0.0105	0.4438	2.4999
Bus16	0.1132	0.0368	0.0986	0.2432	0.9147	0	0	0.0221	0.0059	0.0199	0.0185	0.0076	0.3195	1.8
Bus17	0.0895	0.0291	0.078	1.2336	0.7234	3.3352	0	0.0175	0.0047	0.0157	0.0147	0.006	0.2527	5.8001
Bus18	0.0566	0.0184	0.0493	0.1216	0.4573	0	0	0.011	0.003	0.0099	0.0093	0.0038	0.1598	0.9
Bus19	0.0475	0.0154	0.0413	0.7314	0.3834	2.016	0	0.0093	0.0025	0.0083	0.0078	0.0032	0.1339	3.4
Bus20	0	0	0	0.1665	0	0.5335	0	0	0	0	0	0	0	0.7
Bus21	0	0	0	2.6648	0	8.5352	0	0	0	0	0	0	0	11.2
Bus23	0.1006	0.0327	0.0876	0.2162	0.813	0	0	0.0196	0.0053	0.0177	0.0165	0.0067	0.284	1.5999
Bus24	0.065	0.0211	0.0566	0.6622	0.5251	1.6738	3.4704	0.0127	0.0034	0.0114	0.0106	0.0044	0.1834	6.7001
Bus26	0.015	0.0049	0.013	0.1526	0.121	0.3856	0.7995	0.0029	0.0008	0.0026	0.0025	0.2776	0.5221	2.3001
Bus29	0	0	0	0	0	0	0	0	0	0	0	0.3291	0.5709	0.9
Bus30	0	0	0	0	0	0	0	0	0	0	0	0.6948	1.2052	1.9
Total Load	30.7239	28.932	29.305	9.1902	9.8324	18.003	4.2699	0.3072	1.5955	0.2916	0.272	3.5533	6.9447	143.221
Total	48.822	35.974	30.827	16.119	10.424	19.000	4.300	0.518	1.687	0.598	0.558	4.369	13.086	186.280

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