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The Hybrid New Max Flow Min Cut and Gene Algorithm Approach to Determine Energy Storage Systems Location

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***Abstract*—This paper aims to propose a new hybrid tool to perform the optimal location of energy storage systems (ESSs), studies and its application to the 24 bus IEEE system. This developed tool integrates two phases as follows. The first one uses Max-Flow-Min-Cut (MFMC) techniques to limit the search space, and the second uses Gene Algorithm (GA) to identify the final solution. This hybridization between MFMC and GA proved to be very effective and shows good performance to significantly reduce the size of the search space and to identify good quality solutions. The simulation results tested to determine the position of ESSs on the 24 bus IEEE system showed the approache's feasibility in transmission expansion planning (TEP).**

Keywords—Energy storage systems, congestion management, transmission expansion planning, min-cut algorithm.

I. Introduction

In the planning of electricity system development, there are many transmission expansion planning problems have been handle to reach one or a set of objective functions, of which optimization is still the most important part of the plan. There are some of basic planning solution groups, such as power expansion plan (GEP) and transmission grid expansion plan (TEP) [1, 2].

For long-term, TEP is still the necessary solution to solve the planning problem, but this is not always the best solution to address overload and bottlenecks, to aim the stability, reliability [3]. The most common disadvantage of the TEP solution is the high cost and may be limited of extension lines on a pole and compensation for clearance if new lines are required. More aggressive and economical methods, in this case, used to improve the systems such as restructuring [4], controlling power movement with FACTS [5], and cannot be ignored renewable energy source solution [6, 7]. However, each method has its pros and cons to a certain extent, and not all methods can replace the other.

In recent years, renewable energy sources linked to electricity systems such as wind power, solar energy, etc. have been growing quite rapidly [6, 7], and are widely available on major countries in The World. The generation time of these types is not based on electricity demand but on natural conditions. This leads to sometimes the demand is low while energy of sources is still transmitted to the grid, and conversely when the demand is high these cannot produce energy. To solve the above irrational problem, one of the solutions is to use ESSs, which is a type of power needed to pump energy into the power system for a certain period of time when it is needed to supplement at any time [8, 9].

Because of the ability to redistribute the power flow and reduce the load for the power transmission system, the ESSs can address some of the key shortcomings resulting from the development of renewable energy sources as stated. However, the problems are aimed while TEP with energy storage systems (ESTEP), that are location and how much power of ESSs.

The rest of the paper is organized as follows. Section II summarizes the basic methods for solving the TEP problem, thereby proposing ESTEP model and hybrid algorithm to increase the effectiveness of the method. Section III presents the new MFMC algorithm to locate congestion including poor healthiness lines, thereby reducing the search space in the optimal problem. Section IV proposes the mathematical optimization model for the ESTEP problem and the procedure to find out the optimal location of ESSs. Section V provides computational results and discussion on ESTEP for the 24 bus IEEE-RTS systems. And finally, some concluding remarks are offered in Section VI.

II. ESS with TEP Problem

Optimal network expansion has always been one of the most important issues in power system planning, that needs to be solved to achieve the desired goals. Many studies of TEP in the past have given different models and algorithms use to the optimal problem such as mathematical models AC and DC; metaheuristic methods as PSO, GA [2, 10]. Accordingly, in long-term plans, the expanded transmission problem is one of the appropriate solutions. However, in the short term, that capital consumption is quite large while some other positive solutions can be used as temporary solutions, such as using FACT, ESSs, etc [5, 11].

ESS can provide power during the time of overload due to peak load to ensure the power system operates stably without TEP. In addition, ESSs enhances the transmission capacity of the system by increasing the generation capacity, so that the system not only reduces congestion but also reduces pressure on existing power sources, improves operational efficiency, increases reliability, increasing reserve levels and stability of the power system [12, 11].

There are some storage technologies currently in use in commerce, the most basic being the batteries, which are currently the most common type of storage device [12], Other types by flywheels and supercapacitors are also used to where power is needed in a short time. In addition, Pumped Hydro and Compressed Air energy storage types often have large capacity and high energy storage, so they are used in very active electrical systems. Each type of storage technology for specific purposes and conditions is classified as shown in Figure 1.

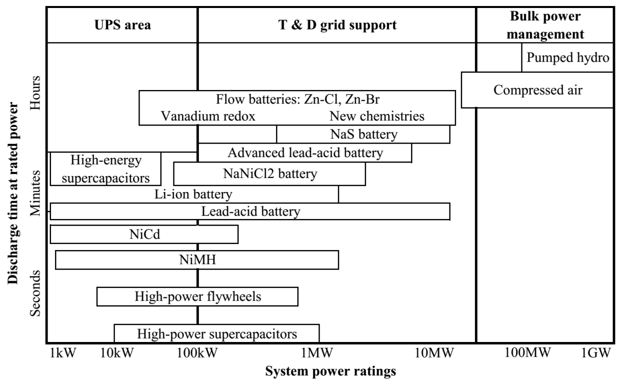

Figure 1: Classification and scope of use of ESSs [6]

Thus, the ESTEP problem should be considered while TEP and disadvantages in the TEP are also disadvantages of the ESTEP. These characteristics correspond to the main difficulties in developing high-performance tools in terms of speed, efficiency and robustness to solve the TEP problems [13]. The literature of this area includes a variety of models and methods to solve the TEP and to address the difficulties mentioned above. These models and methods can be organized as follows:

Classical optimization algorithms: They use decomposition techniques and generally find global optimal solutions for a relaxed version of the original integer problem in which integer investment alternatives are substituted by continuous variables. However, they usually require a large computational effort and therefore they display difficulties to address the expansion of medium and large systems as most of real transmission systems are. In some cases they can also show convergence problems as detailed in [14, 15];

Max flow min cut algorithm (MFMC): The relatively simple MFMC algorithm is used by some studies in the power system to identify bottlenecks in the electrical system [16], or to find the location of the optimum FACTS [5, 16], as well as studying constraints and reliability in the expansion plan of power transmission system [17, 18];

Metaheuristics: They are metaheuristic techniques that are enhanced with particular search procedures in most cases inspired in natural mechanisms. They are especially suited to solve complex and combinatorial problems usually identifying optimal or suboptimal solutions even for large systems, but they are typically associated to large computational efforts [19].

Given the shortcomings of the above approaches, this paper details the application of a hybridizing methodology to address the TEP problem. This hybridization leads to a two-phase combining algorithm. The first phase is termed "The reduction of search space size" and it uses the improved MFMC. In the second phase, called "The refinement of the solution", the Gene Algorithm (GA) is used to find the global optimum solution in the reduced search space, the output of the first phase. This process was designed to overcome the problem associated to large computational effort that is typical to metaheuristics.

III. NEW MFMC ALGORITHM

A. Basic MFMC algorithm

MFMC is an algorithm proposed by Ford and Fulkerson in the 1950s, which determines the smallest slice of a scalar graph, so that the bottlenecks of this graph can be found. By 1997, Mechtild Stoer and Frank Wagner had developed into a Min-Cut algorithm using a computer program [20].

For the power transmission systems, consider the typical model from the problem of determining TCSC location to solve bottlenecks of the transmission system, the basic MFMC algorithm flowchart as Figure 2 (in [5])**Error! Reference source not found.**.

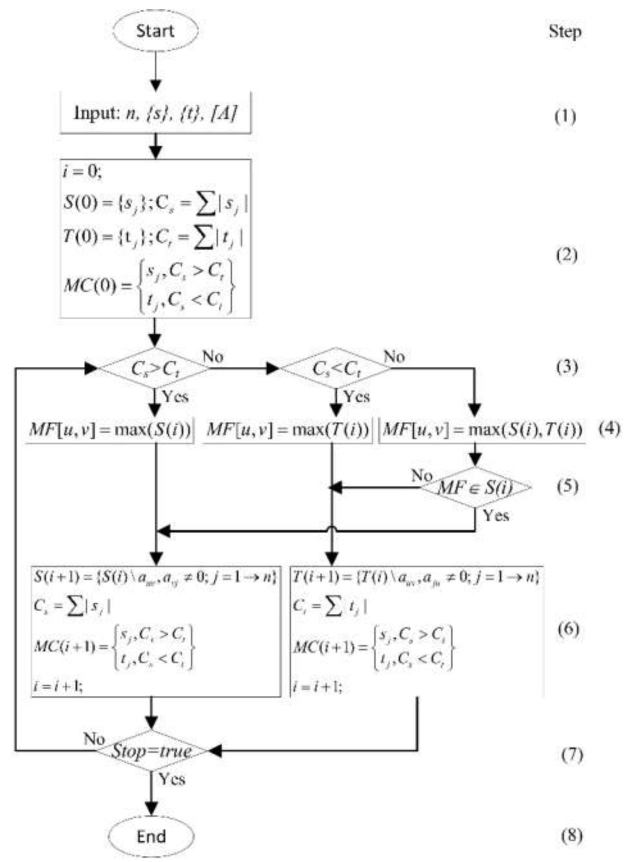

Figure 2: Original MFMC algorithm [5]

Subject to:

- [A] is the matrix (n x n) of magnitude total (here is the rated power of the transmission line) that can be transmitted between nodes, this system has n nodes.
- u, v is the buses u and v.
- {s}, {t} is the set of rate of generators and loads.
- S(i), T(i) is the cut number i from generators and loads direction.
- MC(i) is the set of elements in the mincut at step i.

- MF is maxflow.
- $\sum sj = \sum a_{sj}$, $\sum jt = \sum a_{jt}$ is the magnitude total of generators or loads in the cut number i. And j is the branch in this cut.

B. New MFMC algorithm

The drawback of basic MFMC is that do not include the power flow, which lead to the implementation of problem-solving goals seem to be flawed, such as when selecting lines in the min-cut to solve the congestion problems, it is possible to ignore fullloaded lines. This paper proposes to improve the basic MFMC algorithm by adding the high power branches into min-cut.

In the flowchart at Figure 2, the content should be supplemented with the running of power flow and checking the operation status of the branches. When there are any branches of poor healthiness due to a powerfull flow, them should be noted to update into the min-cut during the algorithm implementation process.

Supplement into step 2 and 6,

- $\left[P_{flow}\right] = runopf(sys)$
- $s_j(new) = s_j + K_j$
- $t_j(new) = t_j + K_j$

where,

$$K_j = \gamma\left(1 - \frac{P_{flow(j)}}{P_{rate(j)}}\right)$$

γ is a factor, which indicates the level of involvement of the power flow distributed across branches.

With the changes presented, each branch will be tested for power flow and results the min-cut including not wellness branches in the power system.

IV. ESTEP Mathematical Model

A. Function fitness

Storage technology has been studied and applied for many years, but the development in commerce is still a problem that needs to be considered carefully because the investment capital for them is still quite high [21]. Determining the location and capacity of ESSs to minimize investment costs is the optimal problem with the following base function fitness:

$$\text{minimize } C^T = \sum_i C_i^T + \sum_j C_j^{ESS} \quad (1)$$

Subject to,

- C_i^T – is the generation cost of source i, calculated by:

$$C_i^T = \sum_{i \in G} c_i(t).A_i(t) \quad (2)$$

- C_j^{ESS} – is the investment cost in the ESS j, calculated by:

$$C_j^{ESS} = \sum_{i \in G_{ess}} P_i^{ess}.c_{ess} + C_0 \quad (3)$$

Constrantion conditions,

- $P_{Gi} - P_{Di} - \sum_{j \in bus} V_i V_j (G_{ij}\cos\delta_{ij} + B_{ij}\sin\delta_{ij}) = 0$ (4)
- $Q_{Gi} - Q_{Di} - \sum_{j \in bus} V_i V_j (G_{ij}\sin\delta_{ij} + B_{ij}\cos\delta_{ij}) = 0$ (5)
- $V_{i\in bus}^{\min} \le V_{i\in bus} \le V_{i\in bus}^{\max}$ (6)
- $S_{i\in branch} \le S_{i\in branch}^{\max}$ (7)
- ESSs location ∈ mincut (8)

Where,

$c_i(t)$ – Power generation cost of the source i at time t.

$A_i(t)$ – Energy of the source i at time t.

t – Period within an evaluation cycle.

P_i^{ess} – Rating power of ESS i.

c_{ess} – Investment rate of ESSs.

C_0 – Investment cost of ESSs are independent.

$P_{Gi}, Q_{Gi}, P_{Di}, Q_{Di}$ – Power of generator and load at node i.

δ_{ij} – Voltage angle deviation between nodes i and j.

$V_{i\in bus}^{\min}, V_{i\in bus}^{\max}$ – Min and max voltage at node i.

$S_{i\in branch}^{\max}$ – Max capacity power at branch i.

B. Hybrid MFMC and GA Algorithm

There are many methods to solve the optimal problem (1), such as mathematical, heuristic and meta-heuristic [10], each of which has advantages and disadvantages, but the fastest finding of global extremes is still a problem that scientists are interested in researching, especially for large systems.

Gene algorithm is one of the fairly common methods used to solve the optimal problem in TEP, but like other meta-heuristic methods, GA calculation volume is quite large and sometimes easily trapped in local extreme. The hybrid between MFMC and GA algorithm proposed in this article will solve the problems of GA algorithm as mentioned. Five steps to implement hybrid algorithm as follows and flowchart at *Figure 3*:

1) Running power flow on the power system.

2) Using the New MFMC algorithm to find min-cut.

3) Determine the search space by limiting the placement of the ESSs at the load nodes of the branches in the min-cut defined at step 2.

4) Using GA algorithm to solve the optimal problem with the function fitness (1) within the search space limited in step 3 and the constraints specified in IV-A.

5) Find the result of the problem is location and capacity ESSs.

V. Test and Discussion

This IEEE RTS system has 10 generators, 24 buses, 36 branches, the electrical data of this system can be found in Figure 4 and reference [22, 23]. When the system loads and generators increases steadily at all nodes to about 60% corresponding to active power 4,560MW and 5,448MW according to table 1 and 2, the system starts to be congested and the 6-10, 7-8 branch are overloaded.

Table 1: Generators in case increase 60%

Bus	P_g (MW)	Q_g (MVar)	Bus	P_g (MW)	Q_g (MVar)
1	307.2	99.84	16	248	86.88
2	307.2	99.84	18	640	160
7	480	120	21	640	160
13	945.6	331.2	22	480	96
15	344	106.08	23	1,056	397.76

Table 2: Loads in case increase 60%

Bus	P_d (MW)	Q_d (MVar)	Bus	P_d (MW)	Q_d (MVar)
1	172.8	35.2	10	312	64
2	155.2	32	13	424	86.4
3	288	59.2	14	310.4	62.4
4	118.4	24	15	507.2	102.4
5	113.6	22.4	16	160	32
6	217.6	44.8	18	532.8	108.8
7	200	40	19	289.6	59.2
8	273.6	56	20	204.8	41.6
9	280	57.6			

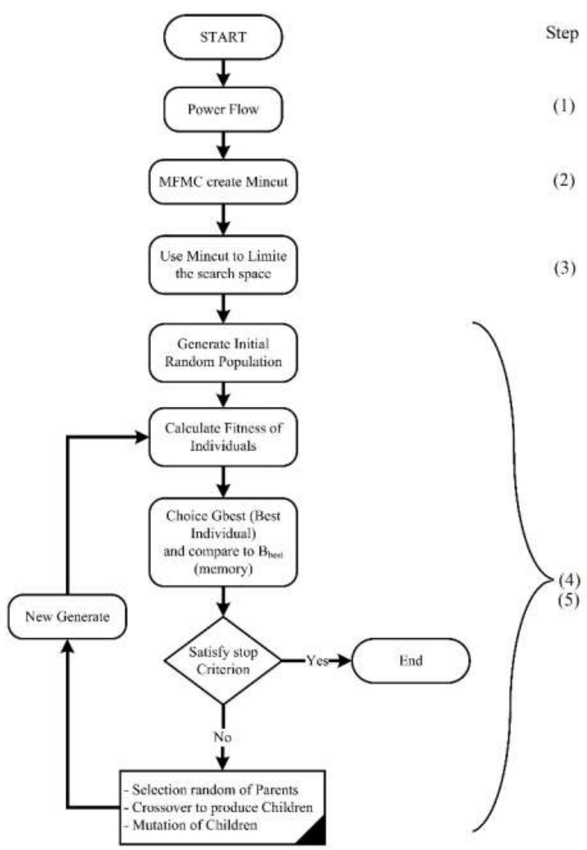

Figure 3: Hybrid MFMC and GA algorithm flowchart

Using Matpower 6.0 software to calculate the power flow as step 1 (presented in IV-B) with 60% increated system, and the MFMC algorithm to determine the min-cut according to step 2 (presented in IV-B). The results are as tables 3 and 4 below.

Table 3: Min-cut result on 24 bus system

	Basic MFMC	New MFMC
Branches into min-cut	8-9 8-10	2-6 6-10 7-8 8-9 8-10

Table 4: Power flow on the branches

Branch	2-6	6-10	7-8	8-9	8-10
Power flow	51%	104%	133%	25%	14%

In table 3, branches 8-9 and 8-10 into the min-cut folowing the traditional algorithm are under-loaded (25% and 14%), while branch 6-10 and 7-8 are overloaded 104% and 133% are left out. According to the New MFMC with γ=175, the 6-10 and 7-8 overload branches are updated into the min-cut, which are the bottlenecks of the system that needs to be considered for better system improvement [18].

Continuing step 3, the search space limit was determined that the ESSs should be installed at the position at the nodes belonging to the branches into the mincut set found by the new MFMC algorithm, which is a set of buses (2, 6, 7, 8, 9, 10), instead of the search space over all system busses.

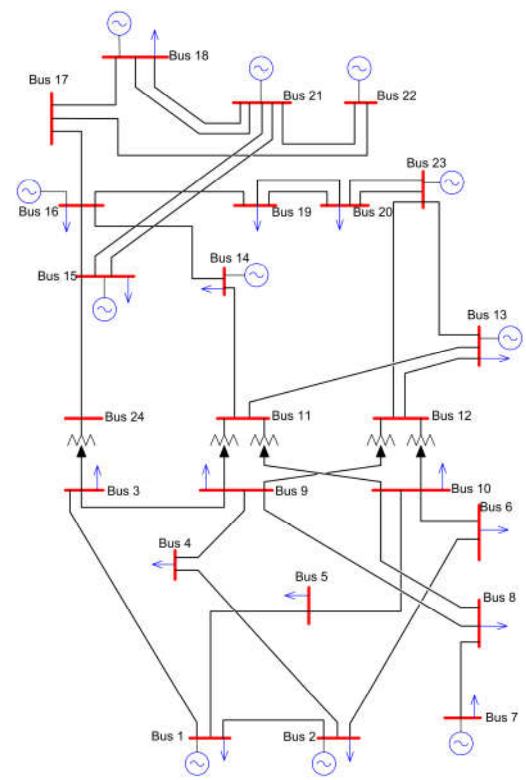

Figure 4: 24 bus IEEE-RTS system

On step 4, solving the optimal problem (1) by GA algorithm corresponding search space limited in step 3, which is the location of ESSs at the set of buses (2, 6, 7, 8, 9, 10) respectively, and the capacity of ESSs increases gradually 10MW per each. The result of step 5 is that 10MW ESSs is located at bus 6 and 30MW ESSs is located at bus 8, the best investment efficiency. This is also consistent with the results of the calculation and check by the method of mathematical power flow AC by Matpower 6.0 software.

VI. CONCLUSION

The expansion plan of the electrical system has always been a concerned problem of strategic planners and scientists because of the importance and effectiveness, especially in the era of strong development technology, which changes both characteristic, space and time in the implementation of policies. Renewable energy and other distributed sources in order to improve the TEP planning are interested by Scientists [8].

The applying ESSs in the power system is posed as a solution to improve the planning of the electricity system, prolonging the time to invest in expanding the system, leading to increased investment efficiency. This is not only financially beneficial, but also has a leveling effect between peak load time and lowest load time, helping to operate electricity system more efficiently, and maximize the exploitation of all types of renewable energy, such as wind and solar.

In this paper, traditional MFMC algorithm have been used, considered and made improvements to overcome its basic defects in the problem of solving electrical system congestion when planning. These results confirm that the hybridization between MFMC and GA used to reduce the search space and to identify the final solution is a powerful tool because it has the ability to find adequate expansion plans in more efficient way. Therefore, future work will be developed in this area namely to continue testing other hybridization combinations and also to pass from a single period static analysis to a multiperiod formulation.

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