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BBO/DE: A Hybrid Biogeography Based Optimization with Differential Evolution for Congestion Management in Restructured Power Systems

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ABSTRACT: In this paper, a hybrid BBO with DE, namely BBO/DE is proposed for Congestion Management. Biogeography based Optimization (BBO) is a new biogeography inspired algorithm, which uses the biogeography-based migration operator to share the information among solutions. Differential Evolution, a fast and robust evolutionary algorithm used for global optimization. The proposed technique combines the exploitation of BBO with the exploration of DE effectively, and this leads to the generation of promising candidate solutions. Performance of our proposed technique is verified using IEEE – 30 bus system. The efficiency and effectiveness of our approach is proved in the experimental results. Performance of BBO/DE is better compared to the performance of other state-of-the-art DE approaches, in terms of the convergence rate and the quality of final solutions.

KEYWORDS: Congestion Management, hybridization, Differential Evolution, Biogeography Based Optimization, Exploration and Exploitability

I. INTRODUCTION

With the increase in global economy, the demand for electric power increases rapidly, which forces the electric utilities to meet the same by increasing their production. The electric power transmitted between two areas in a transmission network is limited by numerous transfer limits such as voltage limits, stability limits and thermal limits. When a restrictive limit is reached at any time, the system is said to be congested. Ensuring the operation of power system within its limits is very important to maintain the security of power system, failing which results in extensive damages with potentially rigorous social and economic consequences. Congestion Management controls the transmission system in such a way that electric power transfer limits are observed. Rescheduling the generator outputs, supply of reactive power support and physical curtailment of transactions are the general methods used to manage congestion in the electric power transmission system. Usually, the first method is preferred by the System Operators.

Numerous methods on Congestion Management have been discussed in literature [2]. The structure of restructured electric power system differs from country to country as well as between different regions of a country. Different models have been reported in [3] to deal with the different transactions, transmission system restrictions, exchanges between properties and energy market's economic efficiency. Congestion Management methods practiced for various types of electricity markets are reported in [4]. A report on prioritization of electric power transactions and the related strategies of electric power curtailment in a power system where pool and bilateral/multilateral contracts coexist is addressed in [5]. A method on Congestion Management which ensures voltage stability is presented in [6]. In [7], an optimal topological design of a power system is addressed as a device to manage Congestion.

In [8], a cost minimization method to manage congestion based on OPF is addressed. In [9], an approach which uses Bender cuts and requires synchronization between generating companies and system operator to manage congestion is proposed. An OPF-based mechanism for alleviating congestions caused by thermal overloads and voltage instability has been addressed in [10]. A cluster based Congestion Management method has been proposed in [11], that groups the transmission system users with correlated effects on the transmission limits.

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The capability of Evolutionary Algorithms (EAs) like evolution strategies, genetic programming, genetic algorithms and evolutionary programming to solve both single and multi-objective OPF-based Congestion Management problems has encouraged the researchers to study and invent new techniques in this field. Natural evolution and survival of the fittest have inspired the idea on EAs, which utilizes a collective learning process of a population of individuals. Randomized operations such as recombination and mutation are used to generate descendants of individuals. Exchange of information between two or more existing individuals is known as recombination, whereas self-replication of existing individuals is known as mutation. According to a fitness measure, individuals with better quality are usually preferred by the selection process than the individuals with relatively worse quality.

Nowadays, hybridization of EAs is becoming trendy due to their capabilities in managing numerous real-world problems. A hybrid BBO with DE, referred to as BBO/DE is projected in this paper to solve the global numerical optimization problems. The proposed hybrid migration operator combines the exploitation of BBO with the exploration of DE efficiently. Experimental results were demonstrated on IEEE-30 bus system.

II. EVOLUTIONARY ALGORITHMS

A. Genetic Algorithm (GA)

Genetic Algorithm (GA) was invented by John Holland in the 1960s and was developed by Goldberg later. Genetic Algorithm (GA) is a search heuristic method that mimics the process of natural evolution. This heuristics is routinely used to generate useful solutions to optimization and search problems. Genetic Algorithm (GA) belongs to the larger class of evolutionary algorithms (EA), which generate solutions to optimization problems using techniques inspired by natural evolution.

The Genetic Algorithm (GA) has four principle components; they are the chromosomes, the fitness function, the crossover operator and the mutation operator. The candidate solutions are represented by chromosomes. New candidate solutions are produced from parent chromosomes by the crossover operator. The parent chromosomes can be selected by the roulette wheel technique. The mutation operator will then be applied to the population and at this point a generation or iteration is completed. The new chromosomes in a population are rated by their fitness measure according to a fitness function. When a chromosome with the desires fitness is formed, it will be taken as the optimum solution and the optimization process is terminated. This process is repeated until the maximum number of generations is reached or the fittest chromosome so far formed is taken to the optimum solution.

GA is useful and efficient in the problem having large search space, scarce domain knowledge, no mathematical analysis and for which traditional methods fail. The advantages of GA are the ease with which it can handle arbitrary kinds of constraints or objective function and adaptability to any kind of optimization problems.

B. Particle Swarm Optimization (PSO)

PSO is originally attributed to Kennedy, Eberhart and Shi and was first intended for simulating social behavior, as a stylized representation of the movement of organisms in a bird flock or fish school.

Particle Swarm Optimization (PSO) is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. PSO is a meta-heuristic that makes few or no assumptions about the problem being optimized and can reach very large spaces of candidate solutions. (PSO) doesn't require the optimization problem be differentiable.

PSO optimizes a problem by having a population of candidate solutions, here said as particles. PSO has no evolution operators such as crossover and mutation. Here the particles fly through the problem space by following the current optimal particles. Each particle keeps track of its coordinates in the problem space which are associated with the best solution (fitness) it has achieved so far. The fitness value is also stored. This value is called *pbest*. Another best value that is tracked by the PSO is the best value, obtained so far by any particle in the neighbours of the particle. This location is called *lbest*. When a particle takes all the population as its topological neighbours, the best value is a global best and is called *gbest*. In PSO concept at each time step, changing the velocity of (accelerating) each particle towards its *pbest* and *lbest* location. Acceleration is weighted by a random term, which separate random numbers being generated for acceleration towards *pbest* and *lbest* locations. This is expected to move the swarm towards the best solution.

The advantages of PSO are that it is attractive as there are few parameters to adjust and requires less computation time and memory.

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C. Differential Evolution (DE)

Differential Evolution (DE), proposed by Price and Storn in 1997 is a powerful population based, simple, direct search algorithm, which uses generation-and-test feature for global optimization problems with real-valued parameters. The information on distance and direction from the existing population is used by DE to direct the further exploration. The advantages of DE are its uncomplicated structure, speed, robustness and ease of use. The first working principle of DE was proposed by Price and Storn in 1997 with single scheme. Later on, ten different schemes of DE was recommended by Price and Storn in 2005 and 2008. DE is superior at exploring the search space and locating the area of local optimum, but it is slow in exploitation of the solutions. DE shows poor performance in locating the global optimum with limited number of fitness function evaluations (NFFEs).

D. Biogeography Based Optimization (BBO)

Biogeography based optimization (BBO) is a new optimization algorithm, proposed by Simon and developed from the theory of biogeography. The study of the geographical distribution of biological organisms is known as Biogeography. Similar to Genetic Algorithms (GAs), BBO is a stochastic global optimizer based on the population of individuals. In original BBO algorithm, the solution of a set of population is represented as a vector of integers. Similar to other biology based algorithms, such as GAs and PSO, the Migration operator of BBO helps in sharing information between solutions. Because of this feature, BBO finds its application in the problems which uses GAs and PSO. However, apart from the above mentioned common features of BBO, it has certain unique features compared with other biology based algorithms, like maintaining its set of best solution throughout the iteration process. BBO was compared with seven state-of-the-art EAs by Simon. He demonstrated the performance of BBO over 14 bench mark functions and a real-world sensor selection problem. The results declare that BBO has good exploitation ability and performs well compared to other biology based algorithms.

III. Proposed Approach: A Hybrid BBO with DE

As pointed out earlier, DE is good at exploring the search space and locating the area of global minimum. However, it is slow exploiting of the solution. On the other hand, BBO has a good exploitation for global optimization. Based on these considerations, in order to balance the exploration and the exploitation of DE, in this work, we propose a hybrid DE approach, called BBO/DE, which combines the exploration of DE with the exploitation of BBO effectively.

A. Hybrid Migration Operator

The key work of BBO/DE is carried out by the hybrid migration operator, which hybridizes the migration operator of BBO with the DE operator, described in Algorithm 1. The core scheme of the projected hybrid migration operator is based on the following two considerations. First, the destruction of good solutions would be less, while poor solutions can inherit a lot of new characteristics from good solutions. In this sense, the existing inhabitants can be exploited adequately. Second, the mutation operator of DE is able to explore the new search space and build the algorithm to be healthier. From the analysis of the results obtained, it can be seen that the hybrid migration operator balances the exploitation of BBO and the searching of DE effectively.

Algorithm 1: Hybrid migration operator of BBO/DE

1: for i = 1 to NP
2: Select uniform randomly $r_1 \neq r_2 \neq r_3 \neq i$
3: $j_{rand} = rndint(1, D)$
4: for j = 1 to D do
5: if rndreal(0, 1) < λ_i then
6: if $rndreal_j[0,1) < CR \; or \; j == j_{rand} \; then$
7: $U_i(j) = X_{r1}(j) + F * (X_{r2}(j) - X_{r3}(j))$
{The original mutation operator of DE}
8: else
9: Select X_k with probability $\propto \mu_k$
10: $U_i(j) = X_k(j)$

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11: end if
12: else
13: $U_i(j) = X_i(j)$
14: end if
15: end for
16: end for

B. *Boundary Constraints*

Title Trial parameters that go against the constraint limits should be returned back from the limit by the quantity of desecration to keep the solution of bound-constrained problems viable. In this work, the following repair rule is applied

$$X(i) = \begin{cases} l_i + rndreal_i[0,1] \times (u_i - l_i) & if \quad X(i) < l_i \\ u_i - rndreal_i[0,1] \times (u_i - l_i) & if \quad X(i) > u_i \end{cases} \quad (1)$$

where

$rndreal_i$ [0, 1] is the uniform random variable from [0,1] in each dimension i.

C. *Main Procedure*

The hybrid BBO with DE technique is formulated by incorporating the aforementioned hybrid migration operator into DE and is described in Algorithm 2. The BBO/DE Compared with the original DE algorithm, BBO/DE requires only a little amount of additional computational cost in sorting the inhabitants and calculating the migration rates. Besides, BBO/DE is capable of exploring the new search space with the mutation operator of DE and in exploiting the population information with the migration operator of BBO. This feature of BBO/DE has made it possible to overcome the deficit of exploitation in the original DE algorithm.

Algorithm 2: Procedure for BBO/DE

1: Generate the initial population P
2: Evaluate the fitness for each individual in P
3: If the halting criterion is not satisfied
4: Sort the Population from worst to best
5: For each individual, map the fitness to the number of species
6: Calculate the immigration rate λ_i and the emigration rate μ_i for each individual X_i
7: Modify the Population with the hybrid migration operator shown in algorithm 1
8: Evaluate the offspring U_i
9: If offspring is better than Parent vector, then replace the parent vector with the new offspring.

IV. PROBLEM FORMULATION

For ever and a day, a cost-effective operation of utilities is favored in a power system. The loads are supplied with electric power by the electric power generators all the way through transmission network and any problems associated to power transmission is well managed by the controlling authority. The power transmission problem consists of two parts in a deregulated market environment. Pronouncement of the preferred schedule by means of optimal power flow is the first part and reschedule of generators for alleviating the congestion is the second part. The key intention of OPF problem is to minimize the fuel rate of generating units for a specific in commission stage so that an optimal generation dispatch is accomplished among the working units and in return the generator operating constraints, line flow limits and system load demand are satisfied.

A. *OPF Problem Formulation*

The objective function for minimizing the fuel cost can be approximated to be a quadratic function of the active power outputs from the generators. Mathematically, it is represented as

$$F_{cost} = \sum_{i=1}^{N} f_i(p_i) \quad (2)$$

where

$$f_i(p_i) = a_i P_i^2 + b_i P_i + c_i, \; i = 1, 2, 3, \ldots\ldots, N \quad (3)$$

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is the expression for cost function corresponding to ith generating unit and a_i, b_i and c_i are its coefficients. P_i is the real power output of ith generator. N is the number of online generating units.

Depending upon assumptions and realistic implications, this constrained OPF problem is subjected to a diverse range of constraints. These include power balance constraints, feasibility of real and reactive power generation, voltage limits at load buses and line flow limits. These constraints are broadly classified as equality and inequality constraints and are discussed below.

B. *Equality Constraints*

1) Power balance constraints: This constraint is based on the principle of equilibrium between total system generation and total system loads that is given by the set of non-linear power flow equations as:

$$\sum_{i=1}^{Ng} P_{gi} = P_d + P_L \quad (4)$$

$$\sum_{i=1}^{Ng} Q_{gi} = Q_d + Q_L \quad (5)$$

where

P_d - total active load

Q_d - total reactive load

P_L - active power loss

Q_L - reactive power loss

Active power loss is calculated based on loss coefficient $P_L = P_{gi} B_{ij} P_{gj}$ (6)

where

B_{ij} - loss coefficients

C. *Inequality constraints*

1) *Generator constraints:* The output power of each generating unit has a lower and upper bound so that it lies in between these bounds.

Active power generation of i^{th} power producer is represented as follows:

$$P_{gi}^{\min} \le P_{gi} \ge P_{gi}^{\max} \quad (7)$$

where

$P_{gi}^{\min}$ & $P_{gi}^{\max}$ - lower & upper limits of active power for i^{th} power producer

Reactive power generation of i^{th} power producer is represented as follows:

$$Q_{gi}^{\min} \le Q_{gi} \ge Q_{gi}^{\max} \quad (8)$$

where

$Q_{gi}^{\min}$ & $Q_{gi}^{\max}$ - lower & upper limit of reactive power for i^{th} power producer

2) *Voltage limits:* The voltage magnitudes of each and every load buses after conducting the load flow simulation should be verified between its bound. This voltage is having its own lower and upper bound and mathematically represented by

$$V_i^{\min} \le V_i \ge V_i^{\max} \quad (9)$$

where

$V_i^{\min}$ & $V_i^{\max}$ - lower & upper limits of voltage at each PQ bus (0.94 p.u & 1.06 p.u).

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3) *Transmission line flow constraints:* The active power flow on all transmission lines should be within its line capacity given by MVA ratings. This can be given as

$$Pl_i \le Pl_i^{max} \tag{10}$$

where

Pl_i^{max} - maximum rating of ith transmission line

Pl_i - active power flow in ith transmission line

D. *Congestion Management*

The key role of System Operator (SO) in an open access competitive electric market environment is to preserve the reliability and security of the electric power system, meanwhile taking economical decisions on market players. These contracts are either modeled as bilateral transaction between two buses or as multi-lateral transactions between many buyer and seller buses considering the system power balance conditions in mind.

The bilateral transaction between a pair of buyer bus 'j' and seller bus 'i' can be modeled as

$$P_{Gi} \cdot - P_{Dj} = 0 \tag{11}$$

where

P_{Gi} – amount of power injections added at seller bus i

P_{Dj} – amount of power taken at buyer bus j

The multilateral transaction can be modeled as

$$\sum P_{Gi} - \sum P_{Dj} = 0 \tag{12}$$

Market players submit their preferred transactions to the System Operator (SO). SO checks the submitted transactions for possibility without any infringement on the transmission limits. If any violation exists, the mechanism of Congestion Management should be implemented to operate the electric power system in a safe mode. In this paper, real power generations are rescheduled from the chosen schedule for alleviating congestion in the transmission network. Each generating unit submit incremental and decremental bidding cost to the System Operator, which is useful in calculating the minimum cost required to alleviate congestion, termed as congestion cost. Mathematically, it is represented as

Minimization of total congestion cost

$$F_2 = \sum_{i=1}^{Ng} C_i^+ \Delta P_{gi}^+ - \sum_{i=1}^{Ng} C_i^- \Delta P_{gi}^- \tag{13}$$

where

$C_i^+ \,\&\, C_i^-$ - incremental & decremental bidding cost of the ith power producer

ΔP_{gi}^+ & ΔP_{gi}^- - incremental & decremental change in power from preferred schedule power to rescheduled power of the ith power producer

$$\sum_{i=1}^{Ng} \Delta P_{gi} = 0 \tag{14}$$

In this paper, the rescheduling of generations is done by hybrid BBO with DE algorithm.

The steps involved in the Congestion Management process are described below.

Step 1: Read the data of System load and generation
Step 2: Conduct load flow studies using Newton Raphson method
Step 3: Identify overloaded transmission lines
Step 4: Select outputs of scheduled generators as state variables
Step 5: Select the control parameters of hybrid BBO with DE
Step 6: Select population size
Step 7: For each individual in the population, evaluate the fitness

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Step 8: Sort the population from worst to best
Step 9: Calculate the rate of incremental and decremental bidding cost
Step 10: Modify the population with the hybrid migration operator
Step 11: Evaluate the offspring
Step 12: If the offspring obtained is better than the parent vector with the new offspring.

V. Results and Discussion

The proposed method of hybridized BBO with DE is utilized to solve the problem of rescheduling of generators to alleviate congestion management. In this paper, the problem of congestion is shown in two cases and is solved by hybridized Biogeography based Optimization with Differential Evolution algorithm. Here the problems of congestion are discussed for two different cases, line 1 -3 outage and generator 2 outage. The best values of all parameters together, in terms of minimization of generation cost and computational efficiency are chosen for the operation of the hybridized BBO/DE algorithm for solving the different congestion cases.

A. *Description of Test System*

The IEEE 30 bus system consists of 6 generators buses, 24 load buses and 41 transmission lines. System data are taken from [Appendix]. The real load of the system is 283.4MW and reactive load is 126.2MVAR. The load bus voltages are maintained between 0.9 and 1.1 p.u. Price bids are submitted by Generating Companies (Gencos) for test system according to which rescheduling of generators occur.

TABLE I

PREFERRED SCHEDULE – IEEE 30 BUS SYSTEM

Parameter	HBBO	BBO	PSO	GA
Pg1(MW)	129.7701	130.3547	132.8335	129.4688
Pg2(MW)	49.9959	49.5085	48.7154	49.7916
Pg3(MW)	29.9966	29.9231	27.9978	29.7168
Pg4(MW)	24.9990	24.9966	24.5414	24.7285
Pg5(MW)	24.9990	24.9799	24.8972	24.9749
Pg6(MW)	30.0152	30.0338	30.9911	31.0951
Loss (MW)	6.3758	6.3966	6.5765	6.3757
Fuel Cost ($/Hr)	829.8086	829.4914	827.5633	830.6707
Emission (Kg/Hr)	344.4623	344.6950	346.5229	344.3316
Total Cost ($/Hr)	1539.9	1540.0	1541.9	1540.5
Std TC	0.0071	0.0357	1.3068	0.5268

Case A: Single line outage
A transmission line connected between buses 1 & 2 is congested due to the line outage between buses 1 & 3.
Case B: Single generator outage
A transmission line connected between buses 1 & 3 is congested due to the generator-2 (at bus 2) outage and line loading limit is reduced 130MVA to 50MVA.

TABLE II

POWER FLOW IN CONGESTED LINE

Case	Congested Line	Line Flow Limit	Before Rescheduling	After Rescheduling			
				HBBO	BBO	PSO	GA
Case A	1 - 2	130	131.9958	129.68	129.59	124.77	129.52
Case B	1 - 3	50	54.5834	48.38	48.40	47.17	48.45

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TABLE III

RESCHEDULED GENERATOR VALUES – LINE OUTAGE – 1-3

Parameter	HBBO	BBO	PSO	GA
Pg1(MW)	129.688	129.598	124.7787	129.5255
Pg2(MW)	45.8212	47.0000	49.7023	46.0000
Pg3(MW)	36.0214	36.5622	36.4153	36.0501
Pg4(MW)	24.9971	24.3437	23.9487	24.8231
Pg5(MW)	24.9989	24.0000	24.5375	24.1358
Pg6(MW)	30.0013	30.0705	31.9097	31.0000
Loss (MW)	8.1287	8.1753	7.8923	8.1346
Fuel Cost ($/Hr)	846.0751	846.4784	849.9148	846.5801
Emission (Kg/Hr)	347.3568	348.0488	345.8502	347.5369
Total Cost ($/Hr)	1.5621e+003	1.5639e+003	1.5628e+003	1.5630e+003
Congestion cost ($/Hr)	391.678	453.702	646.0275	482.5580

TABLE IV

RESCHEDULED GENERATOR VALUES – G2 OUTAGE

Parameter	HBBO	BBO	PSO	GA
Pg1(MW)	158.8223	158.8845	155.7140	159.0177
Pg2(MW)	0	0	0	0
Pg3(MW)	49.0000	49.0000	49.0000	49.0000
Pg4(MW)	25.0000	24.9834	24.9821	24.8965
Pg5(MW)	24.9991	24.9124	24.9426	24.8743
Pg6(MW)	31.9545	32.0000	35.0000	32.0000
Loss (MW)	6.3758	6.3803	6.2386	6.3885
Fuel Cost ($/Hr)	909.7730	909.7523	913.8190	909.6971
Emission (Kg/Hr)	416.7442	416.8545	413.2465	417.0609
Total Cost ($/Hr)	1.7688e+003	1.7690e+003	1.7657e+003	1.7694e+003
Congestion cost ($/Hr)	3.6555e+003	3.6645e+003	3.6647e+003	3.6753e+003

VI. CONCLUSION

The main intention of this paper is to minimize or alleviate power congestion of the transmission network by rescheduling the active power of generators at minimum cost satisfying the operational constraints. The mechanism of Congestion Management proposed in this paper has been implemented on IEEE 30 bus system. The various cases of congestion have been effectively managed with minimum cost and the system constraints are also maintained. The results obtained are quite satisfactory. Thus it can be said that rescheduling of generators for congestion management is profitable process as it maintains the complete quality, grid security and also takes care of the significance of the consumers without detaching any load.

Altogether, this method is up to standard in the deregulated market scenario both technically and economically.

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APPENDIX

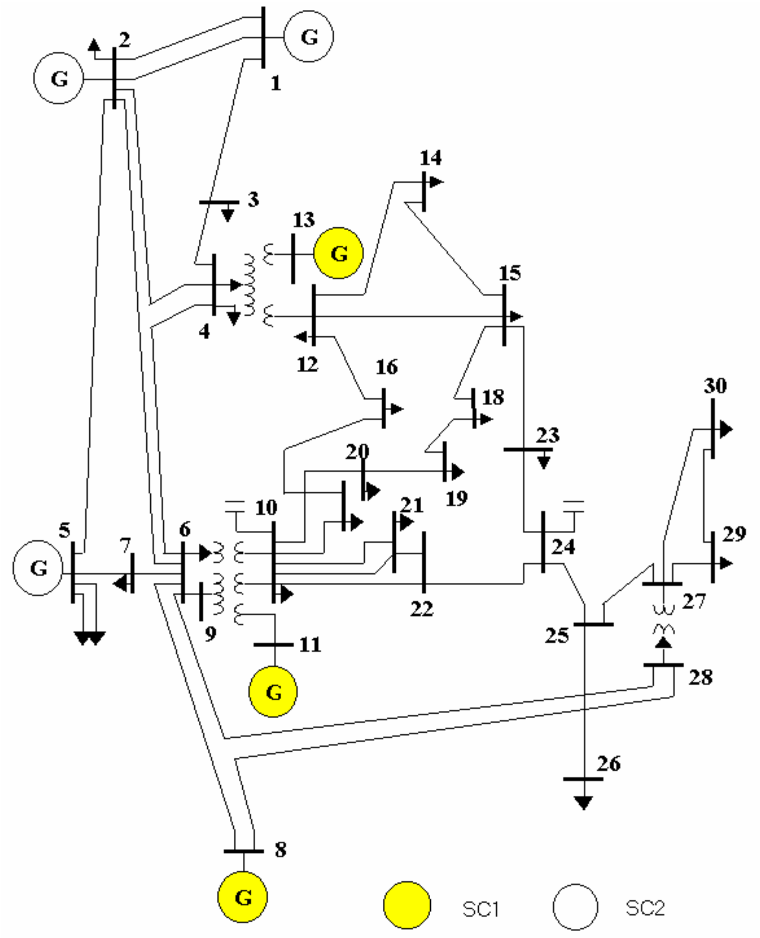

Fig. 1 One Line Diagram – IEEE – 30 Bus System

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