



# Power System Expansion Planning Incorporating Renewable Energy Technologies with Reliability Consideration: A State of Art Literature

Tulasi RamaKrishna Rao Ballireddy, Pawan Kumar Modi

**Abstract:** *The maintenance of power balance condition is one of the key issues to be addressed by the power engineers with day to day increase in the demand for electrical energy, keeping environmental and economical aspects in consideration. CO<sub>2</sub> emitted out to atmosphere from the power plants utilizing fossil fuels causes major environmental pollution. Hence incorporation of carbon capture and storage (CCS) is the need of the hour even though it increase the capital cost. Therefore a decision is to be made by the investing companies either to construct conventional power plants incorporating CCS or to go for non conventional energy sources that are environment friendly. This can be represented mathematically as a Generation Expansion Planning (GEP) problem. Energy Storage System (ESSs) helps in improving the reliability of the system satisfying the economic aspects as well. Also the use of Renewable Energy Technologies (RET) can meet this objective. In view of the complications and complexities involved in the GEP incorporating renewable energy sources with or without storage facility, the Transmission Expansion Planning (TEP) also plays a significant role in the electric power system expansion planning. This manuscript gives a comprehensive review corresponding to power system expansion planning including GEP, TEP and RETs to cope up with the crisis for electrical energy demand satisfying reliability criterion and the application of different optimization methods employed in solving the objective function.*

**Key Words:** CCS, ESS, GEP, Reliability, RET, TEP.

## I. INTRODUCTION

The expansion of the electrical power system may be carried out in three stages, namely (a) power generation expansion [1] (b) transmission network expansion and (c) distribution network expansion.

In most of the cases generation and transmission expansions are given much more priority as the investment cost associated with them is high and also from reliability and stability point of view. The characteristics corresponding to investment on energy generation are (1) Partial or complete irreversibility and (2) High risks.

The formulation of GEP is done so as to determine the solution that states the addition of capacities satisfying different constraints and criterion of reliability throughout the period of planning. Worldwide there is a huge increase in electrical energy generation over the last decade of approximately 22,200TW h as per 2012 and astonishingly fossil fuel plants contribute to about 70 percent of production. As the CO<sub>2</sub> emission is the major concern for the pollution of the environment, the target of decarbonization by 2050 can be met by replacing the conventional energy sources with non conventional energy sources. With their enormous potential, energy from sun (solar) and wind energy can be tapped to a great extent in minimizing the use of fossil fuels and emission of green house gases. The difficulties and problems involved with the inclusion of solar and wind energies can be addressed properly with increase in penetration of RET. The energy stored during the periods of light load or underutilization can be utilized during no power generation periods. By the virtue of their intermittent character, renewable energy sources impose a huge task to the power system to operate stably and reliably. In the recent past ESSs with RETs has gained momentum. All these have been investigated with respect to various aspects [63]. Section II of this presents the GEP and TEP problem statement and the methodological framework of our approach, as well as describes the developed mathematical model. Descriptions of the case study along with the energy storage system of planning are presented in Section III, Finally, Section IV draws upon some concluding remarks.

## II. DIFFERENT VIEWS AND ASPECTS - INVESTIGATION OF GEP & TEP

The generation and transmission expansions are given much more priority as the investment cost associated with them is high and also from reliability and stability point of view. GEP and TEP, both of them are modeled as constrained mixed-integer non linear problem [44].

Manuscript published on November 30, 2019.

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The objective function is expressed in terms of costs associated with new technologies, transmission lines added and reliability subjected to mandatory and optional constraints. The analysis of GEP and are extensively done by taking various aspects into consideration [45].

Some of the issues considered are,

- i. Both GEP and TEP like
  - Solving method
  - Reliability
  - Electricity market
  - Uncertainty
  - Environmental impact.
- ii. Considered only in TEP like
  - Considering distributed generation (DG)
  - The view of time horizon
  - Modeling
  - Line congestion
  - Reactive power planning
  - Flexible AC transmission system (FACTS) devices and
- iii. Defined only in GEP
  - Demand-side management (DSM).

Moreover, the different reviews of TEP and GEP have been briefly analyzed in the following sections 2.1 and 2.2.

## A. Generation expansion planning

Factors like size of the plant to be added, timing of placement, technology associated with the new units, risks involved, constraints etc plays a major role in expanding the generation so as to benefit the investors and is called as a GEP problem [16]. GEP helps in determining the above said factors so as to meet the expected demands fulfilling the reliability constraints for the defined period of operation which is generally 10-30 years. The important

objectives of a GEP include expanding the power system, reduction in total cost of investment and operation, ratio of fuel mix and fulfilling the criterion of reliability. GEP is modeled as a constrained mixed integer non-linear optimization problem aiming to minimization or maximization of the defined objective function subjected to constraints [62, 64]. ESSs are playing a key role in storing the energy in different forms based on the technique used and then converted into electrical energy as and when required. This enhances the reliability of the power system with effective economics. The flow chart for GEP model is as shown in figure 1.

## B. Methods To Obtain The Solution of GEP

Mathematically generation expansion planning is modeled as a constrained, mixed-integer, nonlinear optimization problem. In conventional power system, the aim of the planning is the minimization of cost where as in deregulated scenario, the generation company's looks for the maximization of its earnings with various constraints being satisfied. In a pool market GEP is categorized into master and slave level and the solution to the objective function is obtained for decision making [42] to make sure of systems stability, security, reliability and economics. The most favorable type of generation technology to be installed and optimum level of generation from the units can be obtained from long term GEP problem [62]. The solution of a GEP problem framed with reliability as one of the constraint can be obtained using either mathematical methods [3-6] or Meta-heuristic optimization techniques [7-9] and is demonstrated in figure 2.

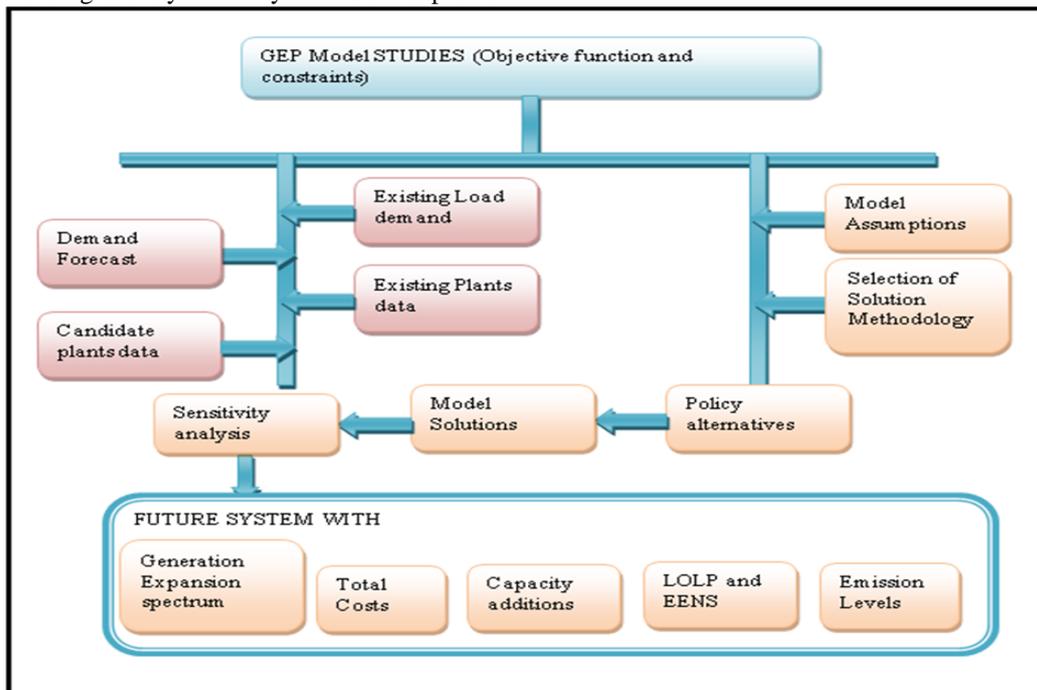


Fig 1: Schematic flow chart for the generation expansion model study [52]

Meza *et al.* [3] presented an Analytic Hierarchy Approach (AHP) to describe and the solution of GEP represented as a long term multi objective model. Ryan *et al.* [4] applied the concept of forward selection in wait and see clusters. In addition a penalty is imposed for not meeting the expected

energy. Moghaddas *et al.* [5] determined the size, location and optimized the indices of reliability. Sirikum *et al.* [6] proposed more effective techniques that has feature of both Genetic Algorithm and Benders Decomposition (GA-BD) method for large scale problems.

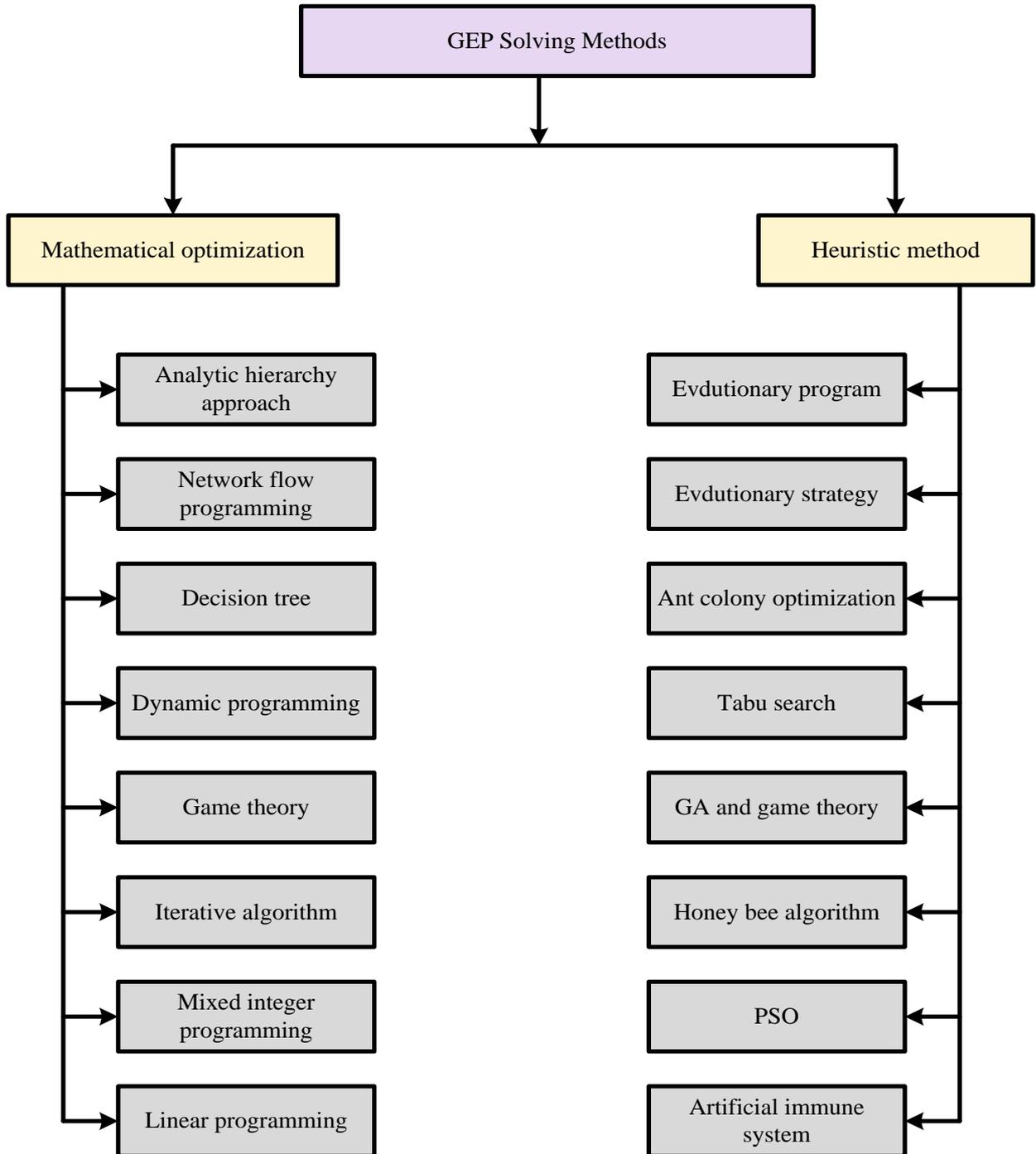


Fig 2: The structure of GEP solving methods

Shuffled frog leaping algorithm (SFLA) is applied to solve a least-cost generation expansion planning problem. Murugan *et al.* [7] treated the GEP as a multi objective functions problem to minimize the cost of investment and maximize the reliability. Hejrati *et al.* [8] found the solution of a five candidate units system with a time period of six years using Honey Bee Mating Optimization (HBMO). Moghddas *et al.* [9] solved the generation expansion problem with the proposed hybrid Modified Game Theory / Particle Swarm Optimization (MGT/PSO) technique. Many constraints with complexity are addressed with acceptable solutions.

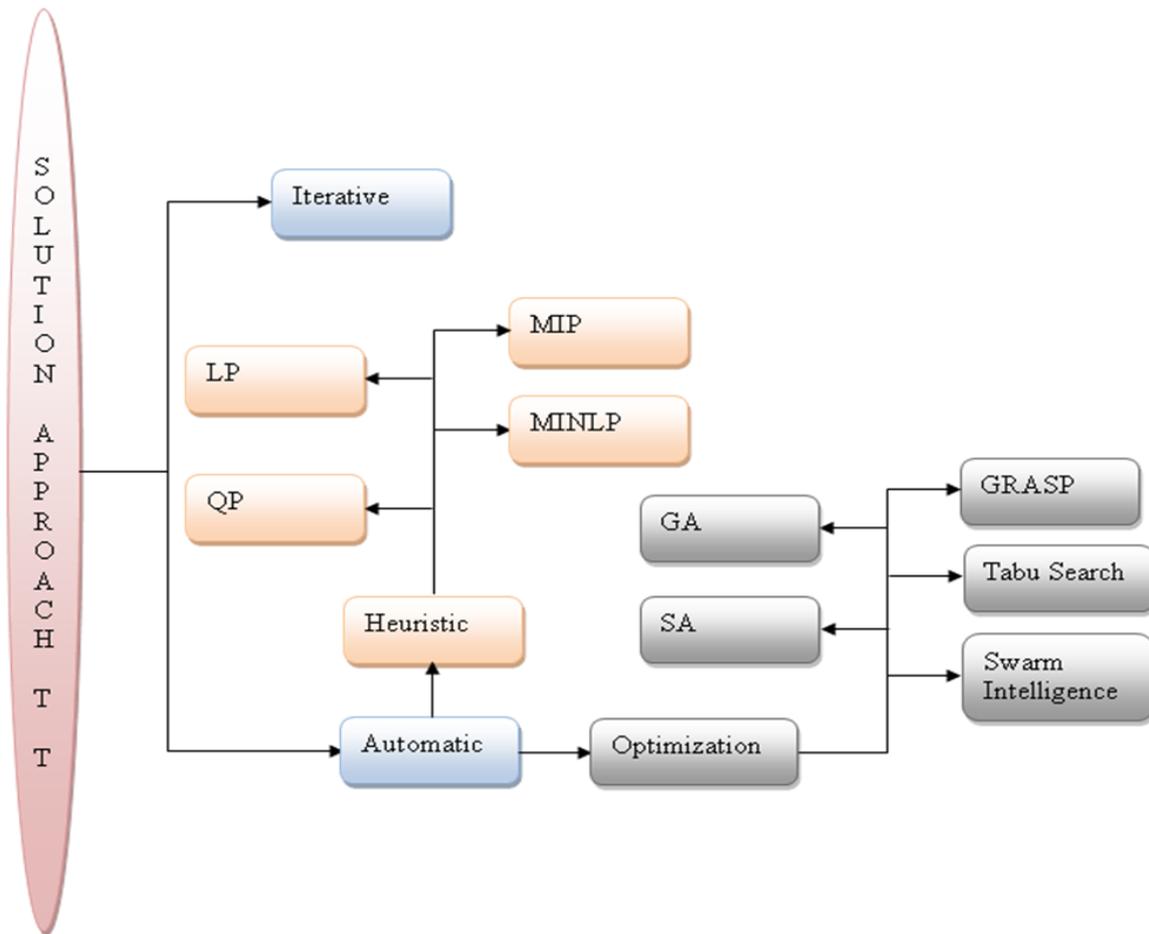
**C. Transmission expansion planning**

Keeping in view of the electrical power demand in the future and the complications and complexities involved in the GEP incorporating renewable energy sources with or without storage facility, the TEP also plays a significant role in the electric power system expansion planning.

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The TEP not only helps in reducing the burden on the existing transmission lines but also increases the reliability of the electric power supply to the substations from where the electric power is delivered to various numbers of consumers through the distribution network. The TEP should be carried in such a way that the power system operates both effectively and efficiently satisfying various operating and reliability constraints. TEP is a process of enabling new lines so as to meet the future demands reliably. Main aim of the TEP problem is to ensure the adequate supply of the future load through optimally expanding and reinforcing the transmission facilities. The TEP problem can be solved by using different approaches which can be tabulated as shown in figure 3 [10]. In figure 3, the automatic scheme consists of Heuristics Algorithms. The heuristics algorithms are considered as the Linear Programming (LP), Quadrature Programming (QP), Mixed Integer Programming (MIP) and Mixed Integer non-linear Programming (MINLP) respectively. The Genetic Algorithm (GA), Simulated Annealing (SA), Greedy Randomized Search Procedures (GRASP), and swarm Intelligence are specified under the optimization process. In the last decade, the proliferation of non-dispatchable renewable energy resources (wind farms) has resulted in more uncertainties and challenges on TEP studies. Stochastic programming (SP) and robust optimization (RO) have been used to characterize the uncertain nature of renewable energy resources within the TEP problem. A linear (dc) power flow in combination with a transportation model is solved suitable for long range transmission planning. Alguacil, N *et al.* [11] proposed a more accurate and flexible linear mixed-integer formulation taking line losses into consideration. Leou, R.C [12] proposed a multi-year transmission expansion model under a deregulated market environment considering investment costs, load curtailment costs, and operation costs and the problem is solved using genetic algorithm. An optimization model for long range transmission planning apt for both static as well as dynamic modes of planning, which includes various costs and system security constraints is studied and a disjunctive mixed integer formulation with better conditioning properties that reduces the computational difficulties to a great extent is applied. This formulation was studied so that valid inequalities can be efficiently dealt with, using branch-and-cut schemes within the Branch and Bound code. Tor, O.B *et al.* [13] evaluated investment costs along with the operation cost due to congestion by describing a multi-year TEP model. Roh, J.H *et al.* [14] portrayed the volatility of the availability of the generating and transmission lines, and the load forecast uncertainties using a stochastic long-term planning formulation by applying Monte Carlo simulation and scenario reduction techniques. The communication between the GENCOs AND TRANSCOs and between the Independent System Operator (ISO) and market participants is simulated using Benders decomposition and Lagrangian

relaxation methods. This technique provides information to the investors regarding the positioning of the new generation and transmission amenities. Fickle nature of the load is analysed by modeling a multi-stage stochastic TEP problem in which the transmission planning is carried out by choosing the available transfer capability (ATC) as the criterion. Roh, J.H *et al.* [15] proposed a market-based model and the efficiency of the technique are tested on a two bus system and 30-bus system. Choi, J *et al.* [16] presented a practical methodology for selecting the best suitable transmission expansion design by making use of an alternative security criterion based on different specifications of contingencies which minimizes the total investment cost and other operational costs of the system. Garces, L.P *et al.* [17] proposed a methodology for TEP using a bilevel model which makes the possibility of energy trade minimizing the investment cost. Hariyanto *et al.* [18] presented a decentralized and simultaneous planning of both generation and transmission, based on cooperative game theory in order to provide a scope for cooperation between various participants with the objective function of maximizing payoff distributed to each participant in the system.



**Fig 3. Various methodologies and techniques for the solution of TEP problem**

Xiaotong *et al.* [19] proposed a model to investigate the negotiations that exist between the generation and transmission known as single-stage deterministic model which is based on game theory. Bustamante *et al.*[20] proposed a heuristic algorithm that can be operated in multiple steps simultaneously to obtain the solution of the TEP. Probabilistic approach and Dynamic Programming is applied to overcome the problems of the size and the complexity of procedures for optimizing the power system. Leite Da Silva *et al.* [21] proposed Ant Colony Optimization (ACO) technique to obtain the solution of the TEP. It was also found that the concept of reliability plays a significant role in the decision making and future expansion planning as well. Rezende *et al.* [22] proposed a metaheuristic optimization technique based on the Artificial Immune System (AIS) to obtain the solution of a multi-stage TEP with the objective of minimizing the investment cost and transmission ohmic losses. TEP with transmission surplus capacity and network load factor unlike the conventional cost based planning where the load levels are neglected and hence some lines operate on high load factors is studied. Georgilakis *et al.* [23] proposed a market based TEP suitable for deregulated environment comprising of two interrelated problems, solved using an Improved Differential Evolution (IDE) model which produces the global optimum as compared to simple Differential Evolution (DE) and the Genetic Algorithm (GA). Zhao *et al.* [34] proposed a novel TEP which provides flexibility to the planning in order to meet the challenges in the deregulated market. It was found that by defining the proposed method as a multi objective optimization problem (MOO) it was able to optimize

multiple objectives simultaneously. The feasibility of the method is successfully tested on IEEE 14-bus system. Shuffled frog leaping algorithm is applied to the TEP to determine location, type and number of new lines that are required in addition to the existing lines to meet the future load demands reliably. Also the performance the proposed method is compared with other heuristic techniques such as particle swarm optimization (PSO) and GA. Silva Sousa *et al.*[25] proposed a good quality, fast, reliable and adequate constructive heuristic algorithm that comprises fuzzy systems and the ranch-and-bound method. Jalilzadeh studied the TEP including the voltage levels through the transmission line by making use of the decimal codification genetic algorithm (DCGA) which has been applied on Garver's 6 bus network. It was found that not only the operational cost decreases significant but also the system delivers power to the load centers satisfying the security and reliability constraints. Cadini *et al.* [26] improved the electrical transmission network to get the best location and type of new lines so that the reliability of the transmission system is maximized without increase in the cost of investment. Yang solved transmission problem using monte carlo simulation and GA. Youssef H.K.M developed an efficient and accurate model for the long range transmission planning which is applicable for both static as well as dynamic methods of planning.

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The method is validated by testing it on IEEE 6-bus test system. Gil, H presented a reliable technique to obtain the solution of the TEP using GA. Mahdavi made use of the decimal codification genetic algorithm to discover the role of static transmission network expansion planning (STNEP) taking the expansion of substation into consideration from the view point of voltage level due to which the overall expansion cost of the system is decreased. Inflation rate and load growth factor is incorporated in the study of STNEP for the first time, because of which the total expansion cost comprising of expansion and operational cost can be calculated more precisely and moreover the system supplies the electric power to the load centers safely and reliably. A mathematical model in connection with a metaheuristic method to solve the transmission network expansion planning (TNEP) by making use of an AC model along with reactive power planning (RPP) is developed. The proposed method was fruitfully tested on IEEE 24-bus system and a real south Brazilian system. A multi objective TEP is solved using GA technique. In addition the best planning scheme is determined by using a fuzzy decision. Foroud *et al.* [27] presented a dynamic expansion methodology to overcome the challenges and complexities introduced due to the restructuring of the power system. Maghouli *et al.* [28] presented a static expansion methodology to overcome the problems associated with the deregulated power system. The multi objective problem is solved using NSGA-II technique which produces more flexibility in the planning. Greedy Randomized Adaptive Search Procedure (GRASP) is used to obtain the solution of the TEP. The proposed method operates in two phases as construction phase and a local search phase. Verma *et al.* [29] proposed a robust and efficient technique by name harmony search for solving TNEP with security constraints. The potentiality of the method is authenticated by applying it to a three bus system and compared the results obtained with other metaheuristic techniques. Shayeghi *et al.* [30] solved the STNEP by including investment cost into fitness function constraints by making use of discrete particle swarm optimization (DPSO) algorithm. Four level TEP model is designed in the partly deregulated environment where only generation is deregulated. Practically the proposed method may not be suitable always but it provides a clear approach to the behavioral changes in the system. STNEP is solved using a hybrid simulated annealing (HSA) that obtains a quality

solution 61% faster as compared to the standard simulated annealing(SSA).

## D. Power System Reliability

Providing uninterrupted and reliable electric power supply economically to the end users is the key role of the electrical power system. In the event of periodic maintenance and outages forced due to failures, continuity in the power supply is maintained by having in built additional or redundant generation capacities [68]. To set an equilibrium between economics and reliability constraints, various plans and operation criterions and methods are employed that include: (i) Planning generating capacity (ii) Operating capacity (iii) Planning network capacity. The criterions that are employed to take care of the failures that occur randomly are by nature deterministic [69]. The distinct aspects of probability include:

- (i) Forced outage rates of generating units.
- (ii) The failure rate of an overhead line.
- (iii) All planning and operating decisions are based on load forecasting technique.

Typical types of uncertainties are as shown in figure 4 [31]. The reliability indices helpful in estimating the electric power supply interruptions are :

- Loss of load probability (LOLP)
- Loss of load frequency (LOLF)
- Loss of load duration (LOLD)
- Expected energy not supplied (EENS)

The reliability assessment is depicted below in figure 5. Concept of reliability plays a major role in the long term GEP or TEP. According to Jin Lin *et al.* [32], integration of non renewable energy sources with the conventional generating sources reduces the consumption of fossil fuels besides the reduction of risks associated during the operation [51].

## III. ENERGY STORAGE SYSTEM PLANNING

Figure 6 depicts the storage of electrical energy in various other energy forms.

ESS has to exhibit different characteristics for being used in various applications [60]. Renewable energy sources form the basis for the technologies to be employed for the storage of electrical energy [47].

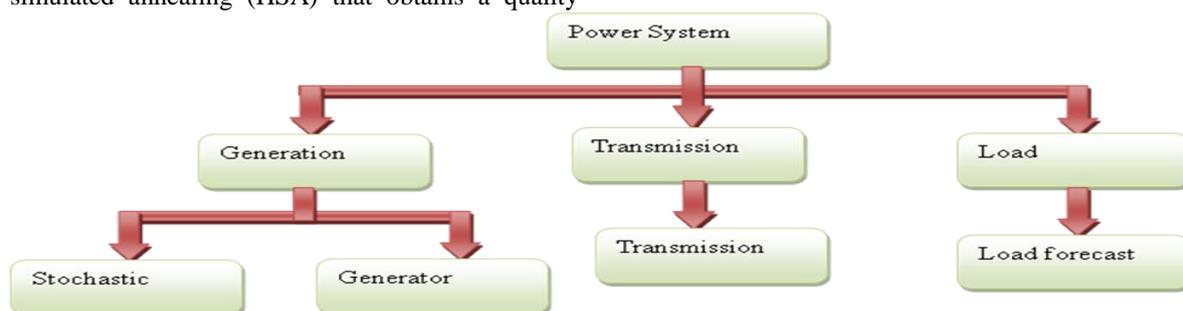


Fig 4. Typical uncertainties in power system.

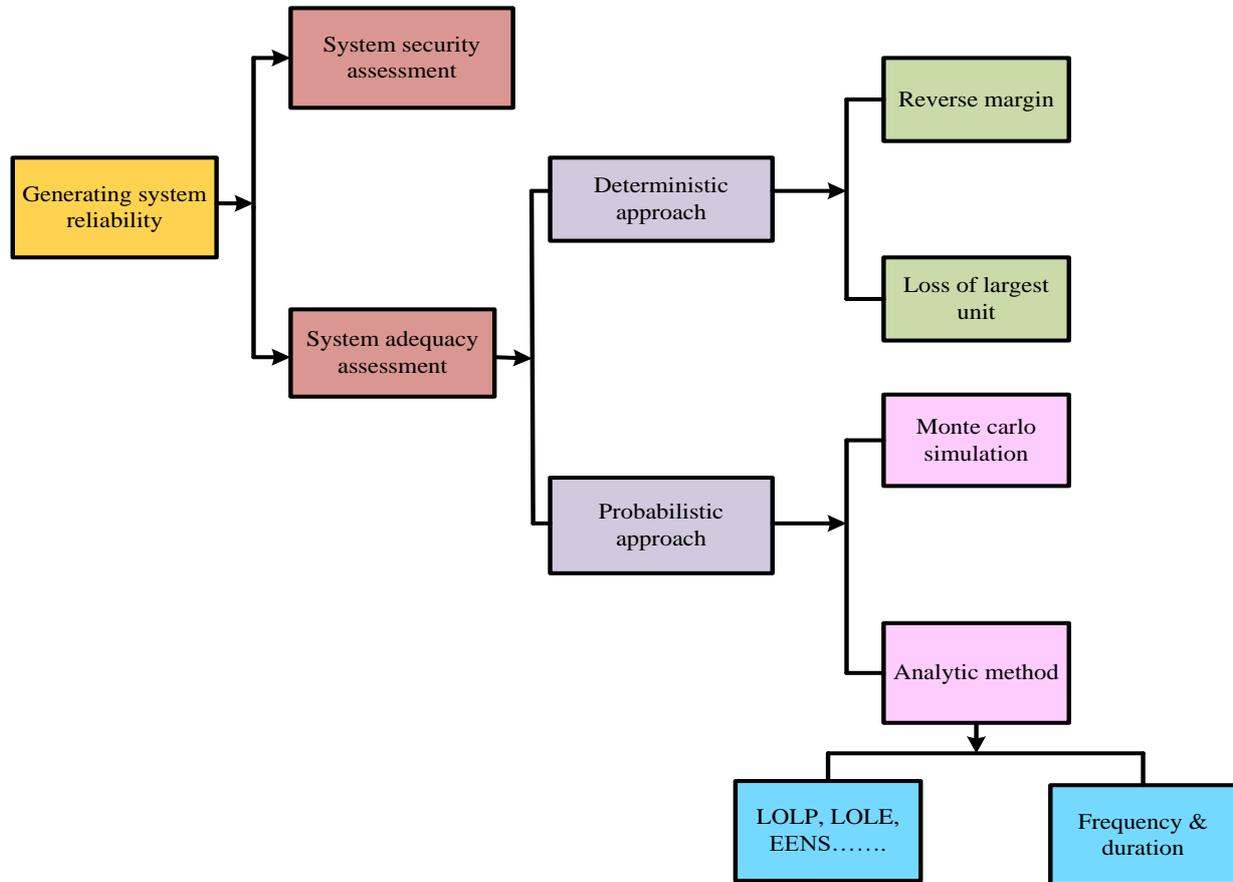


Fig 5. Reliability Assessment

**A. GEP Using Renewable Energy Sources**

The incorporation of non conventional sources like solar and because of their huge potential can not only reduce the usage of fossil fuels but also the carbon emissions to the atmosphere. With proper selection of energy storage devices in terms of storage and finances, can minimize the problems associated the uncertain nature of renewable energy sources. In order to match the generation and demand, these storage devices plays a major role by storing energy when there is ample generation and supplying during low or no generation periods [57]. The solar energy being the fast growing RES in replacing the conventional plants and the encouragement provided by the government to promote the usage of renewable energy sources is bringing a dramatic change in the mindsets of investors [67]. Muneer *et al.* [33] discussed the role of the technological advancements for solar photo voltaic systems to have large stride in Ontario, Canada. The architecture of solar PV system is depicted in figure 7. Modeling of GEP carried in four hierarchy levels is studied for solar power plant along with storage facility and also the strategies to be employed for integrating the renewable energy sources with respect to investment is discussed by K. Rajesh *et al.* [34]. Equivalent Energy Function Method is applied to evaluate the reliability indices like Loss of Load Probability (LOLP), Expected Energy Not Served (EENS). Hernandez *et al.* [35] proposed a robust technique that requires reasonable memory for the Photovoltaic Grid-

connected Systems (PVGCSs) in feeders. The effect of integration of solar power plants with the existing conventional plants is demonstrated by Rajesh K et al. [36] as the future energy demand globally increases by one-third from 2011 to 2035. Besides solar, wind energy is another form of renewable source which is picking up its importance as an alternative source. It is also anticipated that the wind energy increases from 2.6% to 18% by 2050 as per the International Energy Agency (IEA) with reduction in the cost of wind energy [37]. Wind energy constitutes one third of the total investment cost, hydro (27%) and solar PV (23%) [38]. The manufacturing cost of wind turbines might be decreased to an extent of 15% because of significant increase in the generation of wind energy . As per the statistical analysis, the cost of production of one unit of energy is reduced to 20% of the initial cost. As compared to the application of wind energy 3000 years ago, now the situation has changes a lot and it has become more reliable. The developments of wind farm technologies are presented in [39,40]. The problems associated with the intermittent characteristic of wind energy can be overcome by Hybrid renewable energy systems (HRES) techniques and models [41].

**B. GEP problem statement:**

The objective is to minimize the cost of investment cost and operation subjected to certain constraints by using the optimized decision vectors throughout the planning horizon. The extension of the unit commitment problem is to control decisions pertaining to the minimization of the cost of investment and operation.

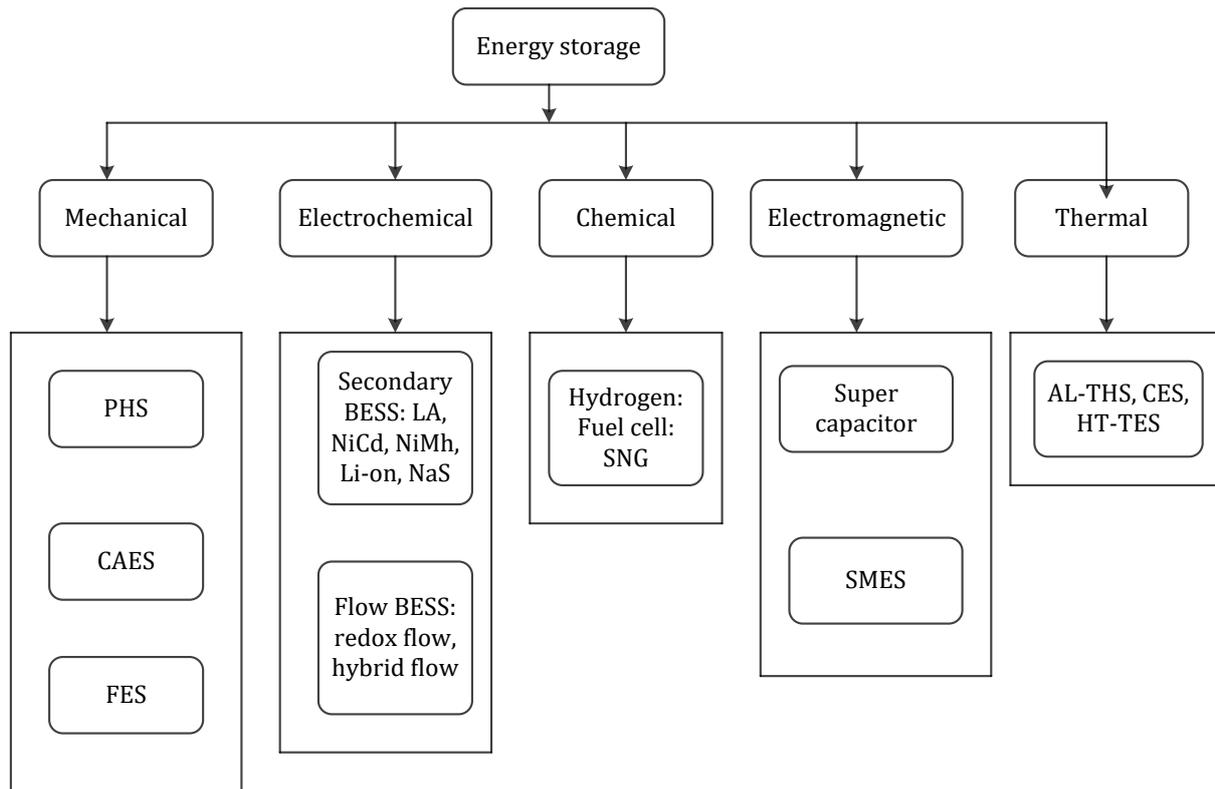
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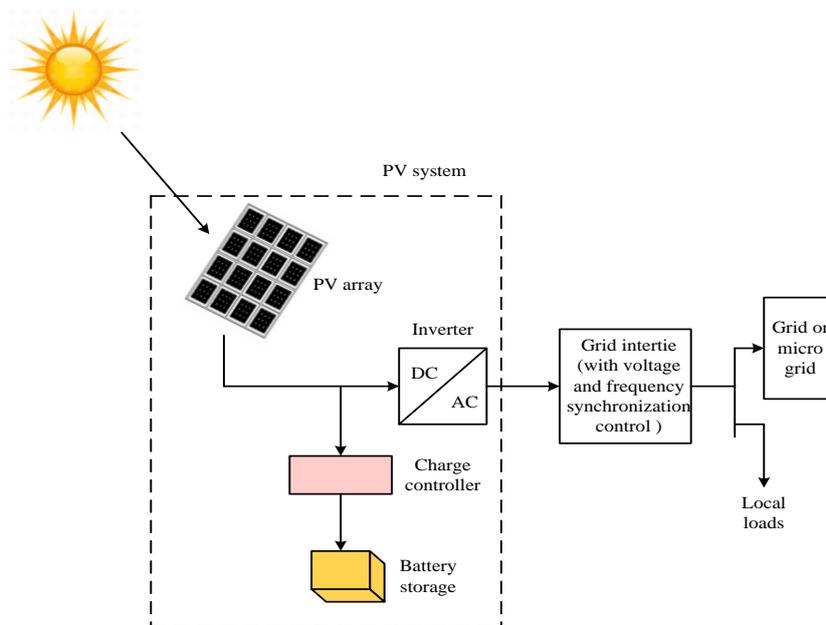
## Generation Expansion Model:

The modeling of C-UC-CE plays a major role in enhancing decision making regarding to investment into expansion of power system. The objective is to minimize the cost of

investment cost and operation subjected to certain constraints by using the optimized decision vectors throughout the planning horizon[66].



**Fig 6. The classification of energy storage techniques**



**Fig 7. The architecture of solar power energy generation**

The model presented here considers a single bus bar system without constraints of transmission. Therefore the decisions to be made include (a) generating unit to be built each year, (b) units to be committed during a period of time, (c) power to be generated by each unit. This decision making helps in defining alternative plans for futuristic needs. For a system integrated with variable renewable energy, the optimization problem is the minimization of total cost of investment and

operation over a planning period. It can be defined as follows.

$$\min \sum_{x=1}^x \left[ \frac{C \ln v_x}{(1+r)^x} + \frac{CO_x}{(1+r)^x} \right] \quad (1)$$

The cost of investment in a year x can be expressed as,

$$C \ln v_x = \sum_{g=1}^{NG} \sum_{t=1}^x C_{l,g}^{inv} IG_{l,g} \quad (2)$$

and the cost of operation for each year is described in (3) [121],

$$CO_x = \sum_{t=1}^T \left( \sum_{g=1}^{NG} C_x^{var} P_{x,t,g} + \sum_{g=1}^{NG} C_g^s S_{x,t,g} + C_{UD} \cdot LS_{x,t} \right) \quad (3)$$

**Demand constraint:**

The reliability of the system is ensured if the total power output of all the plants meets the demand satisfying the constraints throughout the period of planning. Mathematically it can be formulated as shown below in (4) [49].

$$D(X) = \sum_{i \in N_{pump}} P(X,i) - \sum_{pump \in pump} P(X,pump) + Psrp(X),$$

For :  $X = (t, tri, h)$

(4)

Where,

D (X) – represents the demand for the time period (h) and trimester tri (MWh),

Psrp (X) – power generated from all special regime producers (SRPs) that includes co generation in for the time period (h) and trimester tri (MWh),

Npump – set of power plants excluding pumping plants (set of pumping plants) [58].

**Case Analysis:**

A model analysis is done on the basis of research work described above. The GEP problem considers Solar Plant with No Storage (SPWNS) and Solar plant with Storage (SPWS) with FORs 76% and 6% for SPWNS and SPWS respectively. All the plants are categorized into High Emission Plants (HEP-Oil, LNG, Coal) and Low emission Plants (LEP-Nuclear and Solar). The model analysis is depicted in figure 8 [61].

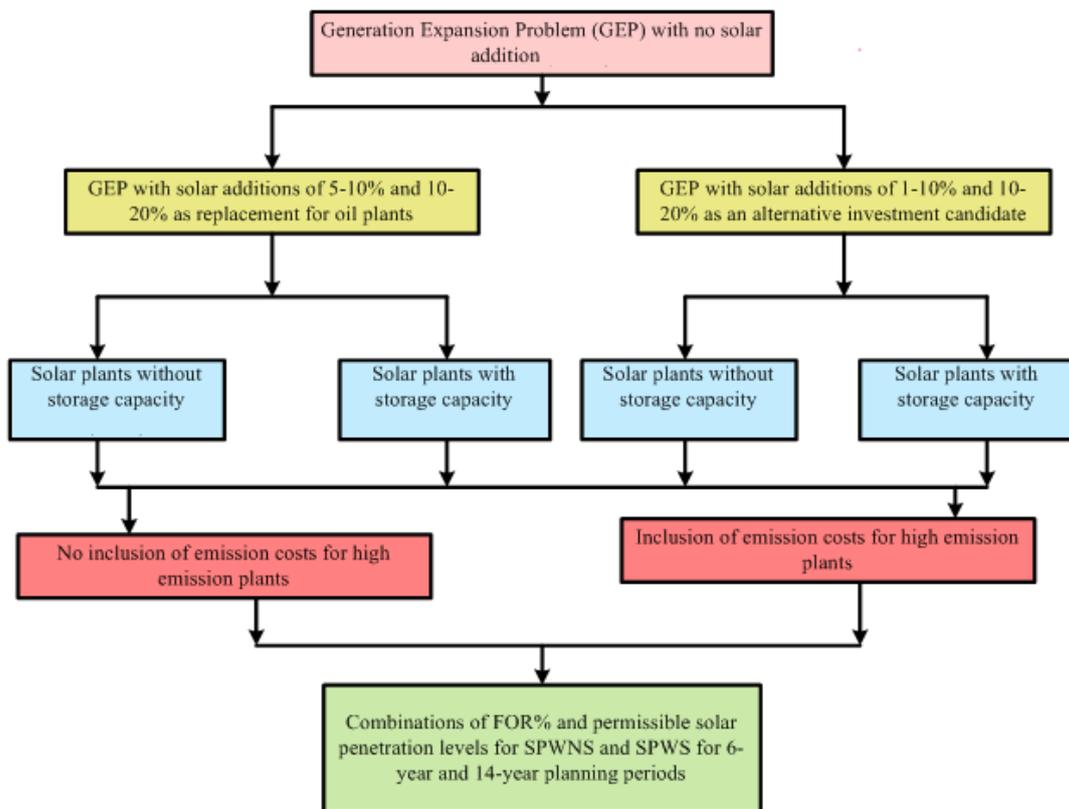


Fig 8. The case analysis for GEP problem

**C. TEP with renewable energy storage system**

The computational complexity can be reduced to a great extent by considering the transmission line losses to be negligible but on the other hand it affects the accuracy of the TEP solution adversely. The effect of line losses in the optimal expansion of transmission can be summarized as follows [54,56]. “Free” power transfer: Considering the losses to be negligible, ignores the cost of operation of

transmitting power. It may result in reduced expansion cost but it increases the network losses. Hence line losses are to be considered to have a balance in the transmission expansion so as to minimize the cost [52]. *Hiding congested lines:* Inclusion of transmission losses implies additional power flows besides additional power generation.

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In the event of losses neglected, the congested lines might appear to be uncongested and in turn leads to exclusion of such lines from the expansion. This may result in a different transmission expansion solution. *Changes to generator dispatch profile*: The order in which the generators are to be dispatched is significantly influenced by the losses and also affects the solution [53]. The impacts of losses discussed above have been presented in detail [70]. With the inclusion of losses, a balance between various cost components involved is achieved. Also additional costs are to be considered to account for congestion and losses. Researches are being done for the reduction of line losses and improve the electrical energy storage.

## IV. CONCLUSION

The key aspect of power system expansion is to maintain the power balance for the present as well as future needs also. A comprehensive review is done here in this paper to bring out the researches carried out regarding the generation of electric power across the globe. It also includes the concept of reduction carbon emissions to the atmosphere, reduction of fossil fuels by integrating existing plants with non conventional sources. The integration of renewable energy source was possible because of the advancements in technology. Evaluation of reliability of the system is also presented. As the renewable energy sources are intermittent in nature, storage of energy during light load periods has become crucial and for which ESSs are employed. Load leveling is the major advantage of using ESSs besides providing superior flexibility and control over the interconnected systems. Application of various optimization techniques to find solution of the GEP problem is presented. At present many investors are lining up to invest in the installation of renewable energy sources because of the rapid changes that took place in the recent past. Governments are also encouraging the use of non conventional energy sources by providing some economic benefits. The integration of renewable energy sources with the conventional plants along with ESSs has to maintain the power balance satisfying various constraints like reliability criterion minimizing the overall cost.

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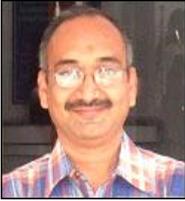
# Power System Expansion Planning Incorporating Renewable Energy Technologies with Reliability Consideration: A State of Art Literature

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