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Governing Distributed Generators and FACTS in Restructured Power system for System Adequacy using Genetic Algorithm

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Abstract*: This paper presents a novel technique for optimizing distribution generators in the restructured power systems and estimate the system adequacy and security through various power system reliability indices. The main objective of this paper is to identify the right location to place reserve generators along with the FACTS devices strategically in the deregulated power system. The weaker portion in the restructured power system network will be identified and the distributed generators and the FACTS devices will be placed in the weaker portion in the network to improve the stability and minimize the losses. The optimal location to comprise the DGs can be done by the composite optimal load flow analysis. The control modes of the FACTS devices are also optimized to achieve the loss reduction in restructured network. The problem defined as a multi-objective power system optimization problem and solution is presented through Genetic Algorithm. The Proposed method is applied to 14 bus system and the simulation results are verified using optimal power flow solution in the Electrical Transient Analysis Programming Tool. The sensitivity of DGs on corresponding locations with different groupings were compared to achieve the optimum values. Results reveal that the proposed method yields better results which can apply in the deregulated power system. The system Adequacy and security also verified in the deregulated power system with the inclusion of DGs and FACTS.

***Index Terms*: Distributed Generation (DG), Genetic Algorithm (GA),EENS.**

I. INTRODUCTION

The installation of DG is playing a vital role in restructured systems due to their powerful effects on power networks. Distribution Generators along with the FACTS devices possess several advantages in terms of loss reduction and improving power quality in the deregulated power network. The introduction of DG's and FACTS in the restructured system evolves fine solution on reliability. The adequacy and system security of the deregulated power system should be optimal for the feasible operation and the power system planning. Photovoltaic cells, Wind turbines, Battery Storage, Micro turbines, Diesel Generators, Fuel cells etc. are used as distribution generators to enhance the power system reliability, For the expansion of the deregulated power network always needed the optimal solution to emphasis the placement of distribution network and FACTS devices.

Many works were carried out to reduce the losses in the restructured power system [1] and [2]. The size of the distribution generator were calculated to achieve minimum losses in the power system network. [3]. An effective method to investigate the optimal size of Distribution Generators using GA and the right location to place DG's were depicted [4], [5]. There are many FACTS devices were employed to analyze power system reliability in the network operation. The FACTS devices like Static Var Compensator, Static Compensator, Static Synchronous Series Capacitor and Unified Power Flow Controllers were analyzed and the enhancement of power system reliability was given [12].

This paper provides the detailed analysis of optimal placement of DG's in restructured systems. The impact of FACTS devices in the deregulated power system network is addressed. Here Unified Power Flow Controller is used to analyses the system stability. Genetic Algorithm is used to identify the right location to place the DG's and Unified Power Flow Controller. The parallel and series control modes of Unified Power Flow Controller are optimized and the corresponding load index gives the system reliability.
The changes in the voltage profile and the reduction in losses in the test system is generated. This paper explains the loss reduction and the improvement in the voltage profile in the two test systems, IEEE 14 bus system. The multiple distribution generators and FACTS devices will improve the system adequacy and system security. The loss reduction the test system tends to escalate the reliability index which implies the reduction of failure rate.

II. DISTRIBUTED GENERATION AND FACTS

In the deregulated power system, DG is a feasible alternative for new capacity especially in the competitive electricity market environment [6]. In the restructured power system distribution generators plays a vital role since the DG's are operated by the Distribution Companies and it is regulated by the independent system operators. The aggregators in the distribution companies have the autonomy to establish different types of distribution generators in the load side [7]. Different types of FACTS devices can be employed to obtain the optimal results in power system reliability.

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But Unified Power Flow controller is very effective in controlling parallel and series parameters in the power system network. Unified Power flow controller has five modes of operation, but the effective results can be achieved at Reactive power Injection mode and Voltage Control mode [12]. The improvements of transmission capability, when the DG's are installed at the right location are addressed [8]. The size of DG's and the significant role of reduction in power losses in the transmission network are addressed. The implication of reverse power flow, if the DG's are not located at the right are is explained [9]. Reliability assessment in the bulk electrical system through chronological simulation stretches the boundaries of loss reduction. The reliability indices obtained through the chronological simulation explains the failure rate and the corresponding power system reliability [10].

In this paper, the conventional results of power flow solution without installation of DG's and FACTS devices were evaluated. The DG's are installed at the weaker portion the test system depends on the evaluated results from GA. Be contingent with the vigorous aspects of the weaker portion in the test system, more DG's can be installed. The power regulation and the fluctuation in the test system also identified and the FACTS devices are also added along with the DG's to regulate the power flows. The reliability indices are also checked to stabilize the system with adequacy and security which are the back bone of power system reliability.

III. PROBLEM FORMULATION

The objective function of the optimization problem is to identify the total power loss of a restructured or deregulated system. It will determine the minimized power loss which will be subjected to the constraints as follows:

Minimize: $P_{Loss}(x)$

$$P_{Loss} = \sum_{k=1}^{NS} Gk\ (|V_i|^2 + |V_j|^2 - 2|V_i||V_j| cos(\delta^i - \delta^j)) \quad (1)$$

$$P_i = |V_i| \left| \sum V_k \right| \left[G_{ik}\, cos(\theta_i - \theta_k) + B_{ik}\, sin(\theta_i - \theta_k) \right] \quad (2)$$

$$Q_i = |V_i| \left| \sum V_k \right| \left[G_{ik}\, sin(\theta_i - \theta_k) + B_{ik}\, cos(\theta_i - \theta_k) \right] \quad (3)$$

Subject to Constraints

Power loss limit

$$P_{Loss}^{With\ DG} < P_{Loss}^{Without\ DG}$$

DG Power limit

$$P_{DG}^{min} \le P_{DG} \le P_{DG}^{max}$$

IV. PROPOSED ALGORITHM

The appropriate placement of DG's in the restructured power network is very essential to cater the losses and power system stability. The primary objective is to locate the right positioning of DG and FACTS devices in restructured system. The paper will provide the impacts of Distribution Generators and optimal operation of FACTS devices in restructured power system with respect to total power loss reduction.

A. *The chromosomal encrypting configuration*

The chromosomal encrypting configuration is devoted to optimize the power flows through Genetic Algorithm to distribution Companies is shown below

Location (Node Number)	Size (Max MW)

Fig. 1: Chromosome encrypting for placing one DG

Unit 1 Location (node number)	Unit 1 Size (MW)	Unit 2 Location (node number)	Unit 2 Size (MW)

Fig. 2: Chromosome encrypting for placing two DG

Unit 1 Location (node number)	Unit 1 Size (MW)	Unit 2 Location (node number)	Unit 2 Size (MW)	Unit 3 Location (node number)	Unit 3 Size (MW)

Fig. 3: Chromosome encrypting for placing DG and FACTS

The element or the position is the location of the node in which DG is connected. The bus parameters will be taken from the corresponding buses where the DG's are installed. The element two denotes the size of the DG to be installed at the weakest portion. The representation of bus in the given system and the corresponding size of the generator is shown in figure 1.The size of the given DG ranges from 0 to 4000 KW. For the installation of two DGs, two new pairs of genes are added to establish the chromosomal encryption as shown in the figure 2. The encryption for the addition of two DG's and a FACTS device in the GA is shown in Figure 3. The population evolved from one generation to another will takes place with the defined mutation.

B. *GA and Network Parameters*

Table 1: Network parameters

GA Parameter		Network Parameter	
Population Size η_{pop}	80	DGs and FACTS power rating range P_{DG}	0-4MW
Maximum Generation (Gen_{max})	30	Maximum number of DG	2
Crossover Probability Ω_c	0.9	Maximum number of FACTS	1
Mutation probability	0.04		

V. BASE CASE COMPUTATION - IEEE 14BUS SYSTEM

The power flow solution using Newton-Raphson method is carried out for IEEE 14 Bus System through Electrical Transient Analysis Programming and taken as a Base Case without installing any DG's or FACTS Devices. The power losses in each bus in the test system and the corresponding voltage profile are shown in the Figure 4 and Figure 5 respectively. The program is coded for the restructured systems with the failure rate are also depicted in the reliability analysis tool in the electrical transient analysis programming.

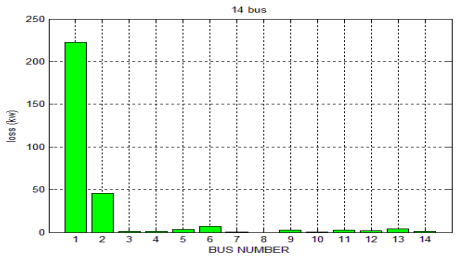

Fig. 4: Total power loss for 14bus system-without DGs and FACTS

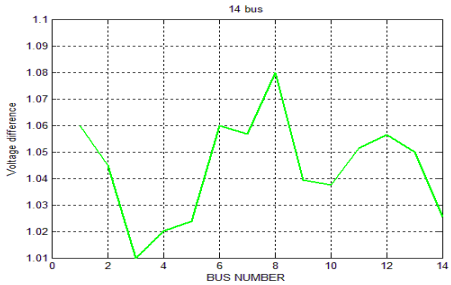

Fig. 5: Voltage profile for 14 bus Without DGs and FACTS

Table 2: DG Optimal Size for 14 bus System

Bus System (14 Bus)	DG Bus location	Optimal DG Size (KW)	System loss with DG (MW)	System loss without DG (MW)	Percentage reduction in loss
Base Case	--	--	--	53.5	--
DG One	11	1056	50.54	----	5.50%
DG One DG Two	4 7	793 749	24.94	----	53.38%
DG One DG Two FACTS	6 4 2	235 273 655	12.67	----	73.23%

A. *Case I – Installing One DG*

Table 2 shows the Optimal size of DG's and FACTS devices needs to be employed which is derived from Genetic Algorithm. The corresponding power losses after installing DG's and FACTS devices in the weaker buses identified by the GA is evaluated. If only one DG is available, GA instructs to install at bus 11 which will give the optimum solution. Table 2 shows that the power loss is reduced by 5.5 Percentage from the base case.

B. *Case II - Installing two DGs*

The available sources for the distribution generation are increased by one unit, GA gives the right position are at bus 4 and Bus 7. Here GA integrates the two DG's and gives the optimum results through the power flow solution. There is a significant reduction in power loss is evaluated after installing two distribution generator at the weakest buses. Table 2 shows a 53.38 percentage of reduction in power losses from the base case. It also concludes that the increase in the number of DG's minimising the power losses which is the corner stone of Deregulated power system associated with the Distribution Companies.

C. *Case III – Installing DG's and FACTS*

Installing DG's and FACTS together in a network plays a vital role in power loss and system adequacy. The system security and the reliability also analysed with the addition of FACTS devices in a network. If the sources at the load side is increased by three units, the units will be encaged by DG's and the third Unit is installed with the FACTS devices. The minimization function in the GA gives that the new sources can be installed at the busses 6, 4 and 2. At bus 6 and bus 4, DG's are installed and the Unified Power Flow Controller is installed in bus two. The modified power flow solution using Newton-Raphson method gives a tremendous reduction in power loss. Table 2 shows that the power loss is reduced to 73.23% from the base case.The reliability index in the restructured power system can be verified with the inclusion of DGs. The interruptions can be calculated using the equation (4), Expected Energy Not Supplied

$$(\text{EENS}) = \sum_{j \epsilon M} (U_j P_j) \quad (4)$$

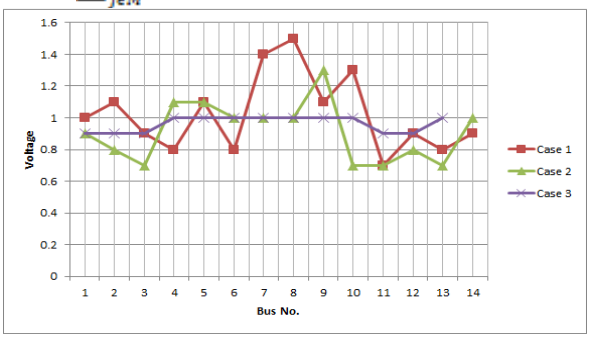

Fig. 6: Voltage Profiles for 14 bus System with DGs and FACTS

The word "data" is plural, not singular. The subscript for the permeability of vacuum μ0 is zero, not a lowercase letter "o." The term for residual magnetization is "permanence";

VI. ANALYSIS IN RESTRUCTURED POWER SYSTEM

The failure rate in the restructured power system can be reduced by the inclusion of DGs at the right location. GA provides the optimum location and the size of the DGs also fixed to avoid the detraction of reactive power in the system.

The derated states are usually combined with the totally forced out state to create a derating adjusted forced outage rate (DAFOR). The DAFOR of a generating unit can be obtained using Equation (5)

$$\text{DAFOR} = \frac{\text{Tdn} \sum_{N\epsilon 1}^{n} (U_x t Y_i) \text{N}}{\text{T}} \quad (5)$$

The adequacy of the system also calculated with the help of reliability index, which will show the interruptions and enables the enhancement of reactive power compensation in the system.

The system average interruption duration index will give the load curtailment in each load bus. SAIFI will be minimized with the proper placement of DGs in the deregulated power system.

$$\text{AIFI} = \frac{\sum_{N\epsilon M}^{n} \left(ENLC_i) + \sum_{N\epsilon L}^{n} \text{ENLC}_i \right)}{\text{N}} \quad (6)$$

The complexity and the transmission deficiency in the deregulated system also minimised with the performance indices with respect to the remedial modifications. The EENS can be calculated from equation (4) which is associated with the other reliability index SAIFI in equation (6). The calculation of load curtailment can be optimised with derating adjusted forced outage rate factor in equation (5). DAFOR can be calculated from the forced outage rate and the failure rate with respect to the two state or three state approach. The chronological simulation is used to identify the EENS from the test systems.

Table 3: EENS with DGs and FACTS

Cases	IEEE 14 – Bus System EENS (MWh/Yr)
Base Case	9178.77
With One DG	8254.67
With two DG	8011.55
With two DG and FACTS	7321.11

VII. SIGNIFICANCE OF RESULTS

The above Table 2 and Table 3 clearly show the effects of DG's and FACTS devise. There is considerable changes in voltage profile and reduction in losses in the test system. The optimal locations for placing the DG's and FACTS device were phenomenal to cater the strength of system at various identities and proper distribution. Table 3 represents the variation of EENS with respect to the optimal placement of DGs in the IEEE 14 bus system. The results can be used for the expansion of power system and power system planning. Reliability of the system also increased with decrease in EENS. The electrical interruptions can be isolated with the proper placements of DGs and the adequacy of system can be maintained. The above result also shows that the transmission of power also very economic with the optimal constrains. When the energy sector is privatized, the analysis using DGs plays a vital role in the Distribution companies.

VIII. CONCLUSION

In this paper, an innovative attitude for the supervision of power system network using DG's and FACTS devices is represented. The proposed method deals with optimal placement of DG's and FACTS. The rating and location has been optimized using Genetic Algorithm. The coding is developed to carry out the mutation at the right location and the algorithm is carried with one dimensional array. The IEEE 14 Bus System is taken as test system and the impacts of optimization in DG's and FACTS is extended with the inclusion of failure rate in the deregulated system. The results oriented with multiple use of DG's and FACTS with is base case is compared. It was shown that placing proper DG's and FACTS devices will be minimizing power losses and improving voltage profiles. The improvement in the EENS with the optimal location of DGs shows the security and adequacy of the system also increased. The results implies the multiple use of DGs and FACTS reduces power losses in a system rather than using a single DG. The system adequacy is achieved with the optimized value of EENS.

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A.k.Parvathy was born in Kerala, India. She graduated from the faculty of Electrical Engineering from Government college of Engineering, Thrissur, Kerala and obtains masters from the same. She completed PhD in Electrical Engineering from Anna University in 2013. Her thesis is "Analysis and Adaptation of Quadratic Linearization to the Control of Permanent Magnet Synchronous Motor". She served as lecturer in Amrita Institute of Technology and Science, Coimbatore for one year. She served as Assistant Engineer in Kerala State Electricity Board and monitored the erection of 220 KV substation in Brahmapuram. She then served as Senior Lecturer in Sri Venkateswara College of Engineering, Chennai. Currently she is serving as the Professor and Head of Electrical Engineering Department in Hindustan University. Her research areas focused on Power system and Power Electronics.