VAR PLANNING FOR VOLTAGE STABILITY IMPROVEMENT USING GENETIC ALGORITHM

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Abstract:

The voltage and VAR issues have become a significant problem in recent years. This is due to the steadily increasing power system sizes, high loading of transmission facilities and abnormal operating conditions arising from inadequate VAR balance. The problem has worsened with voltage instability that arise in mature systems. The blackout events have confirmed the importance of reactive power planning and dispatching in maintaining the security of modern power systems. An algorithm of reactive power dispatch is described which incorporates the voltage collapse proximity indicator to minimize the possibility of voltage collapse in the system.

Keywords: Reactive power planning – Voltage stability – Voltage collapse proximity indicator – Genetic algorithm (GA).

I-Introduction:

Bulk power transfers in electric power systems are limited by transmission network security. The binding security limit can be a limit on line flow, voltage magnitude, voltage collapse or other operating constraint. Under highly stressed conditions the effects of capacitor switching and generator reactive power limits become significant [1].

Utilities in recent days face conflicting demands. On one hand because of economic and environmental reasons there are problems in adding to the generation side, or in getting right of way for more transmission lines for transmitting power. On the other hand the demand for secure and reliable power to customers keeps on increasing. This means that the power system equipment is operating at close to its limits. The interconnection in the power system adds to the complexity of maintaining and running the power system optimally. One outcome of the above factors is the voltage stability and voltage/VAR violation problems [2].

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Voltage stability is the ability of the power system to restore steady state voltages at all buses in the system to their normal conditions after being subjected to disturbances. A system is in a state of voltage instability when disturbances conditions cause a progressive and uncontrollable voltage drop. The main factor causing voltage instability is the reactive power mismatch in the power system [3]. Voltage collapse is the process by which voltage instability leads to a very low voltage profile in a significant part of the system [4]. Voltage/VAR violation problem is characterized by violation of limits in generators reactive power and/or voltages of load buses. If voltage/VAR violations are left unattended or not dealt with properly, there is a danger of voltage/VAR violations developing into voltage stability problem.

Once a new setting of controllers to solve the voltage/VAR violations and voltage stability problems, have been arrived at, a new power flow scenario results. Sometimes, this new power flow scenario may have problems of overload, which has to be avoided [2].

In VAR planning problems, the determination of the candidate buses for installing new VAR sources plays an important role in the final solution. Correct selection of the candidate buses can result in better final solution. A voltage collapse proximity indicator (VCPI) is used to identify weak buses and to choose these weak buses as candidate buses for the installation of new VAR sources [5].

In this paper an algorithm of reactive power dispatch is described which incorporates the voltage collapse proximity indicator to minimize the possibility of voltage collapse in the system. The results show the effect of VAR planning on reducing both the VCPI of load buses and the percentage loading of most of the transmission lines of the network. Also it will be noticed how the voltage profile of the buses which exhibit under voltage violation was improved.

II- Problem Formulation:

The VAR planning problem has been treated as an optimization problem concerned with the attempt to simultaneously improve certain objective function and satisfy equality and inequality constraints. However, it is believed that the objective function that weights the voltages at each load node according to its collapse proximity level as penalty factor is preferable. This is because a higher priority is then given to nodes which are closer to collapse [6,7].

- *objective function:*
  minimize objfunc = power loss cost + capacitor operating cost + p_v+p_Q.

- *The system operation constraints:*

a) Load flow equations (equality constraints):

$P_{gi} - P_{di} = \sum |V_i| |V_j| |Y_{ij}| \cos(\theta_{ij}+\delta_j-\delta_i)$ for i=1--N, excluding the slack bus

$Q_{gi} - Q_{di} = - \sum |V_i| |V_j| |Y_{ij}| \sin(\theta_{ij}+\delta_j-\delta_i)$ for i=1--NG, excluding the slack bus

$Q_{gi} - Q_{di} + Q_{ci} = -\sum |V_i| |V_j| |Y_{ij}| \sin(\theta_{ij}+\delta_j-\delta_i)$ for i=1--NL

b) Inequality constraints:

$Q_{gi\,min} \leq Q_{gi} \leq Q_{gi\,max}$ i=1--NG, excluding the slack bus

$V_{min} \leq V_i \leq V_{max}$ i=1--NL

$Q_{ci} \leq Q_{cmax}$ i=1--NL

Where,

N	Total number of buses
NG	Number of generating buses
NL	Number of load buses
NC	Number of buses with capacitors installed
i, j	Index for buses
P_{gi}	Real power generation at bus i (p.u.)
Q_{gi}	Reactive power generation at bus i (p.u.)
P_{di}	Real power demand at bus i (p.u.)
Q_{di}	Reactive power demand at bus i (p.u.)
Q_{ci}	Reactive power support from new capacitors at bus i (p.u.)
V_i	Voltage at bus i (p.u.)
Y_{ij}	Element of network admittance matrix (p.u.)
θ_{ij}	Phase angle of Y_{ij} (radian)
δ_i	Voltage angle at bus i (radian)
Q_{cmax}	Maximum reactive power support possible to add (p.u.)
Q_{gi}^{min}, Q_{gi}^{max}	Reactive power generation limits at bus i (p.u.)
V_{min}, V_{max}	Limits on bus voltage levels (p.u.)
p_v, p_Q	Penalty terms for load bus voltage and generator reactive power violations.

III- Criterion for Selection of Candidate Buses:

The important issue of the VAR planning problem is to determine the locations for installing new VAR sources. An appropriate selection of candidate buses can both reduce the solution space and obtain a better final optimal solution. A system may be voltage unstable if it includes at least one voltage unstable bus [8] and appropriate VAR planning can enhance the system security margin. In this paper, a weak-bus oriented criterion is developed in order to determine the candidate buses.

In the following, an efficient and simple indicator presented earlier [9] is used to identify weak buses in electrical power system. The indicator is based on a power flow Jacobian matrix, J, which is calculated at the current operating point of the system. The voltage collapse proximity indicator (VCPI) for each load bus, considering reactive power is:

$$VCPI_{Qi} = \sum \Delta Q_{gj} / \Delta Q_{di} \qquad j \in NG\,,\ i \in NL$$

The motivation for this definition is that the voltage is mostly affected by reactive power. For a voltage stable system, all $VCPI_{Qi}$ will have a value greater than but close to unity, while for a system close to voltage collapse, at least one $VCPI_{Qi}$ will become large, approaching infinity at the point of collapse. It is apparent that the weakest bus in the system will have the maximum value of $VCPI_{Qi}$.

IV- Proposed Genetic Algorithms:

Genetic algorithms are inspired by the mechanism of natural selection, a biological process in which stronger individuals are likely be the winners in a competitive environment. They presume that the potential solution of problem is an individual and can be represented by a set of parameters. These parameters are regarded as the genes of a chromosome and can be structured by a string of values in binary form. A positive value, generally known as fitness value, is used to reflect the degree of "goodness" of the chromosome for solving the problem [10].

The algorithm starts from an initial population generated randomly. Using the genetic operations considering the fitness of a solution, which corresponds to the objective function for the problem generates a new generation is generated. The fitnesses of solutions are improved through iterations of generations. When the algorithm converges, a group of solutions with better fitnesses is generated, and the optimal solution is obtained [11,12]. The main components of GAs are:

1. Coding: representing the problem at hand by strings.
2. Initialization: initializing the strings.
3. Fitness Evaluation: determining how fit is a string.
4. Selection: deciding who mates.
5. Crossover: exchanging information between two mates.
6. Mutation: introducing random information.

1. Coding:

Each individual in the population consists of a number of parameters equal to the number of weak buses with relatively high VCPI. Each parameter is binary coded to form the chromosome. The value of each parameter expresses the size of VAR source placed at the selected bus.

2. *Initialization:*

   Fair coin tosses are used to initialize all binary coded strings forming the unrated population.

3. *Fitness Evaluation:*

   All strings are evaluated with the same fitness function. The fitness function incorporates the objective function, i.e., the total cost of the proposed capacitor placement scheme with the cost of real power loss and cost penalties if a string violates any of the constraints. In this way a rated population is formed and GA proceeds such that the fitness function is maximized and, consequently, the objective function is minimized.

4. *Selection:*

   The roulette-wheel selection scheme is used. Each slot on the wheel is paired with an individual in the population. The size of each slot is proportional to the corresponding individual fitness. In such a scheme, a fitter string receives a higher number of offspring and thus has a higher chance of surviving in the subsequent generation.

5. *Crossover:*

   Given a crossover probability, simple crossover is performed to exchange information between strings. In the proposed algorithm single-point crossover is performed.

6. *Mutation:*

   Given a mutation probability, random alteration of genes in a string may occur. For a binary coded string, a mutation represents a simple bit change.

7. *Convergence / Termination of the GA:*

   When the maximum allowable number of generations for the GA is reached the best solution found so far is returned.

Figure (1) shows a complete cycle representing one generation of the search: [13]

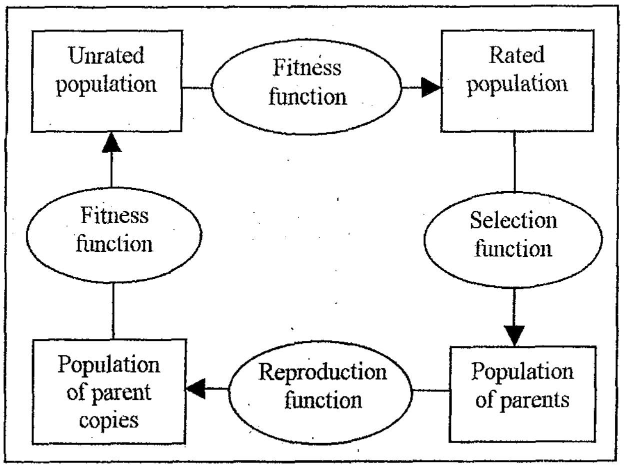

Figure (1): General procedure for all evolutionary computations.

V- Formulation of The Optimal VAR Planning Using GA:

The system tested and described is the IEEE 14-bus system [14]. The following parameters are used for GA:

Population size = 30
Max. generation = 15
Crossover probability = 0.9
Mutation probability = 0.001

The number of parameters that consist the genetic chromosome is determined according to the number of weak load buses at a certain hour. The results of GA are compared with the results which were obtained by applying initial load flow calculations without any compensation.

VI- Numerical Results:

The initial load flow results show that, with no reactive power compensation, there are several weak load buses with relatively high VCPI. After the reactive power planning is completed, the total reactive power compensation is summarized in table1. As shown the VCPI for all buses were reduced and the voltage magnitudes were raised. The reactive power injection take place at the bused with relatively high VCPI. The values of VAR injected were determined using the GA. Figure 2 shows the improvement in the Q-V curve of the weakest bus (bus 14) during the peak load hour due to reactive power compensation. Another result of VAR planning is the reduction of percentage loading of most of the network transmission lines as shown in table 2. It was observed that after compensation the voltage of all buses lied within the specified operating range 0.95-1.05. Figure 3 shows the voltage profile of the weakest bus during the peak load hour before and after compensation.

Table 1: **Voltage magnitudes, VCPI and VAR injected during the hour of peak load**

Bus no.	Initial Load Flow			Genetic Algorithm		
	Volt. (pu)	VCPI	Q_c (Mvar)	Volt. (pu)	VCPI	Q_c (Mvar)
4	0.946	1.068	0	0.95	1.0654	0.8
5	0.996	1.031	0	0.998	1.0296	0
7	0.972	1.084	0	0.982	1.0779	0
9	0.944	1.145	0	0.963	1.1324	1.85
10	0.946	1.14	0	0.962	1.1291	0.15
11	0.978	1.076	0	0.986	1.0701	0
12	0.992	1.045	0	0.996	1.0424	0
13	0.981	1.066	0	0.988	1.0608	0
14	0.923	1.187	0	0.952	1.1606	3

Table 2: **Percentage loading of transmission lines during the hour of peak load**

Line		Initial Load Flow	Genetic Algorithm
From	To		
1	2	73.446	74.42
1	5	74.451	73.909
2	3	36.339	36.677
2	4	56.333	55.158
2	5	4.985	5.181
3	4	18.738	17.988
4	5	44.521	44.324
4	7	47.391	51.878
4	9	24.122	26.383
5	6	56.167	54.423
6	11	57.052	43.371
6	12	48.844	44.201
6	13	69.687	60.343
7	8	65.868	55.14
7	9	61.225	51.618
9	10	4.821	6.589
9	14	35.192	41.123
10	11	42.317	27.096
12	13	33.163	23.587
13	14	43.124	28.59

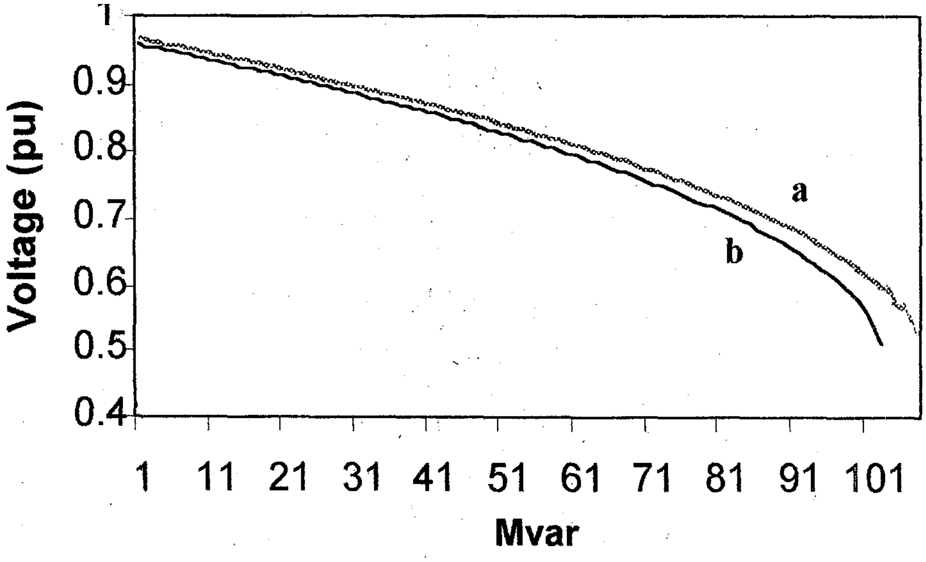

Figure (2): Q-V curve of the weakest bus.
a- with compensation b-without compensation

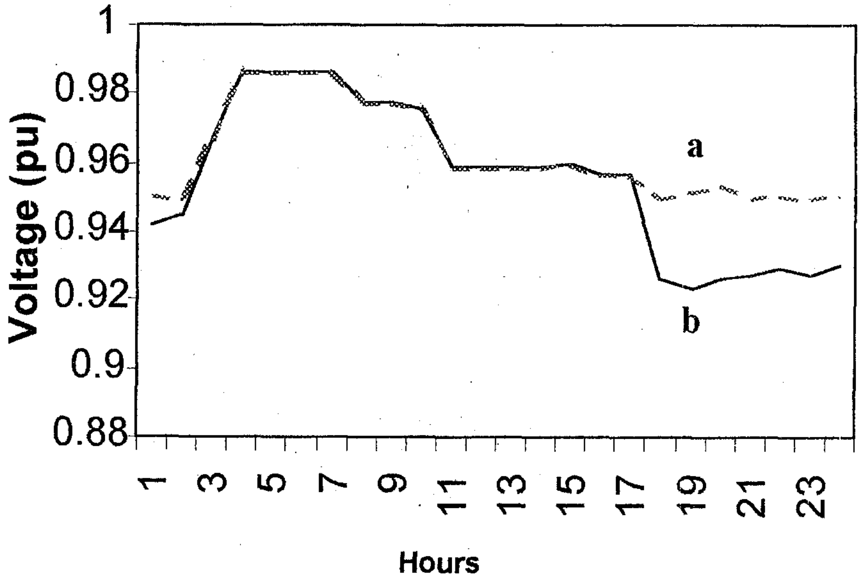

Figure (3): Voltage profile of the weakest bus
a- with compensation b- without compensation

VII- Conclusion:

In this paper, an algorithm of optimal VAR planning is described which incorporates the voltage collapse proximity indicator to minimize the possibility of voltage collapse in the system. The optimal VAR problem was solved by minimizing the total cost, which includes the operation costs of new VAR sources and the cost of transmission power loss. The IEEE 14-bus system was tested. The genetic algorithm (GA) was used to solve such a problem. The VCPI was reduced and the voltage profile throughout the planning period was improved from the under-voltage seen in the initial load flow to the required operation range. It was also found that new VAR sources are installed at or near load buses that exhibit under-voltage violation. The GA is characterized by the lack of assumptions for linearity or convexity. GAs can be applied successfully in many situations where conventional methods fail. They can be applied in situations where a fitness value can be determined from system results. GAs weed out the bad and tend to produce more of the good individuals. Not only they produce more of the good solutions but better and better solutions. This is because they combine the best traits of parent individuals to produce superior children. The resulting analysis accuracy can not be surpassed by any other AI technique. The results show the effectiveness of the proposed technique in the area of power system planning.

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تخطيط القدرة الغير فعالة لتحسين استقرار جهد الشبكة باستخدام خوارزم جينى

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ملخص:

الجهد و القدرة الغير فعالة فى الشبكة أصبحا من المشاكل المهمة فى السنوات الأخيرة و ذلك قد نتج عن التزايد المستمر فى حجم الشبكة و زيادة تحميل خطوط النقل. سبب آخر لهذه المشكلة و يتمثل فى ظروف الغير معهودة نتيجة عدم الاتزان فى القدرة الغير فعالة. و قد تفاقمت هذه المشكلة مع ظهور عدم الاتزان فى جهد الشبكة. أحداث التعتيم الكلى جاءت لتؤكد على أهمية التخطيط للقدرة الغير فعالة للمحافظة على استقرار الشبكة. فى هذا البحث يتم عرض طريقة للتخطيط للقدرة الغير فعالة آخذا فى الاعتبار المؤشر على قرب انهيار الجهد وذلك بهدف تقليل حدوث ذلك فى الشبكة.