COMPUTATIONAL INTELLIGENCE BASED POWER SYSTEM SECURITY ASSESSMENT AND IMPROVEMENT UNDER MULTI-CONTINGENCIES CONDITIONS

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This thesis presents new techniques for voltage stability assessment and improvement in power system under multi-contingencies. A line-based voltage stability index termed as Static Voltage Stability Index (SVSI) was used to evaluate the voltage stability condition on a line. The value of SVSI was computed to identify the most sensitive line and corresponding weak bus in the system. The results obtained from the voltage stability analysis using SVSI were utilized to identify most sensitive line corresponds to a load bus and estimate the maximum loadability and operating margin in the system. The SVSI was consequently used as the line outage severity indicator in the implementation of contingency analysis and ranking. The application of SVSI was extended for the evaluation of the constrained power planning (CPP) and Flexible AC Transmission Systems (FACTS) devices installation using Evolutionary Programming (EP) by considering multi-contingencies occurrence in the system. The minimizations of SVSI and transmission loss are used as two separate objective functions for the development of optimization technique. The effect of reactive power load variation on transmission loss in the system is also investigated. Consequently, the EP optimization technique is extended for the evaluation of the operating generator scheduling (OGS) to be applied on reactive power control in power system. The results obtained from the study can be used by the power system operators to make a decision either to achieve minimal SVSI, minimal transmission loss or minimal installation cost. This has also avoided all generators to dispatch power at the same time. Finally, a novel multi-objective Constrained Reactive Power Control (CRPC) algorithm using the state-of-the-art of EP for voltage stability improvement has been developed. A performance comparison with Artificial Immune System (AIS) in terms of SVSI and loss minimization was made and it is found that the proposed algorithm has been able to produce better results as compared to AIS. The contributions of the studies among the others are the development EP and AIS engine for CPP considered multi-contingencies (N-m), the development of EP and AIS engine for FACTS installation considered multi-contingencies (N-m) for the determination of FACTS placement using SVSI and optimal sizing of FACTS using EP and AIS, the development of new technique for OGS based on EP optimization technique and the development of multi-objective EP and AIS engines for CRPC considered multi-contingencies (N-m).
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\[ \beta \text{: Mutation scale} \]
\[ C_{ci} \text{: Per unit reactive power source purchase cost at bus } i \]
\[ \delta_i, \delta_j \text{: Voltage angles at bus } i \text{ and bus } j \]
\[ \delta_{ji} \text{: Angle difference} \]
\[ e_i \text{: Fixed reactive power source installation cost} \]
\[ f_i \text{: Fitness for the } i^{th} \text{ random number} \]
\[ f_{\text{max}} \text{: Maximum fitness} \]
\[ G_y \text{ and } B_y \text{: Mutual conductance and susceptance between bus } i \text{ and bus } j \]
\[ g_k \text{: Conductance of branch } k \]
\[ h \text{: Per unit energy cost} \]
\[ N \text{: Gaussian random variable with mean } \mu \text{ and variance } \sigma^2 \]
\[ N-I \text{: Single Contingency} \]
\[ N_B \text{: Number of buses} \]
\[ N_{B-I} \text{: Total buses excluding slack bus} \]
\[ N_c \text{: Possible reactive power source installation buses number} \]
\[ N_E \text{: Branch number} \]
\[ N_i \text{: Numbers of buses adjacent to bus } i \text{ including bus } i \]
\[ N-m \text{: Multi-Contingencies} \]
\[ N_{PQ} \text{: PQ bus number} \]
\[ N_{PV} \text{: PV bus number} \]
\[ n_s \text{: Slack (reference) bus number} \]
\[ Q_{ci} \text{: Amount of reactive power either positive (reactance) or negative (capacitance) installation} \]
\[ Q_d \text{: Reactive power loading (reactive load)} \]
\[ Q_{gn} \text{: Reactive power to be injected to generator } n \]
\[ S_{vi}, P_i \text{ and } Q_i \text{: Apparent, active and reactive powers at bus } i \]
\[ S_{vj}, P_j \text{ and } Q_j \text{: Apparent, active and reactive powers at bus } j \]
\[ SVSI_{\text{avg}} \text{: Average fitness (with } SVSI \text{ as fitness)} \]
\[ SVSI_{\text{max}} \text{: Maximum fitness (with } SVSI \text{ as fitness)} \]
$SVSI_{\text{min}}$ : Minimum fitness (with $SVSI$ as fitness)

$SVSI_{\text{set}}$ : $SVSI$ value before optimised CPP

$SVSI_{\text{sum}}$ : Sum of fitness (with $SVSI$ as fitness)

$V_{\text{set}}$ : Bus voltage before optimised CPP

$V_i$, $V_j$ : Voltages at bus $i$ and bus $j$ respectively

$x_{i+m,j}$ : Mutated parents (offsprings)

$x_j$ : Parents

$x_{j \text{max}}$ : Maximum random number for every variable

$x_{j \text{min}}$ : Minimum random number for every variable

$Z_{ji}$, $R_{ji}$, $X_{ji}$ : Line impedance, resistance and reactance

$\theta_i$ : Voltage angle different between bus $i$ and bus $j$ (rad),
CHAPTER ONE
INTRODUCTION

Nowadays, the power transmission systems have been changed a lot. The voltage deviation due to load variation and power transfer limitation was experienced due to reactive power unbalance which has drawn attention to better utilize the existing transmission line. The shortage of reactive power can cause the generator and transmission line failure leading to blackout or collapse in a system [1]. It also causes a higher impact on power system security and reliability [6]. Hence, the electrical energy demand increases continuously from time to time. This increase is due to the fact that few problems could appear with the power flows through the existing electric transmission networks. If this situation is uncontrollable, some lines located on the particular paths might become overloaded [2]. Due to the overloaded conditions; the transmission lines will have to be driven close to or even beyond their transfer capacities. Consequently, the transmission line outage in a power system was reported to be the main issue towards voltage instability as well as generator outage contingency [3-4]. The line outage may cause violations on bus limit, transmission line overloads and lead to system instability [5]. While, the generator outage can be caused by failure of generator; this may interrupt system delivery and lead to system instability [6].

1.1 PROBLEM STATEMENT

Voltage stability has become a concern in power system operation when it involves heavy load and contingencies. It is highly dependent upon the system limits, which leads to the restriction of loading capability of a network. Therefore voltage stability study becomes an important issue in power system planning and operation since it was reported in [7-12] that this problem is a progressive issue which receives major concern. The increment in load demands will decrease the reactive power and voltage, which leads to voltage collapse in the system. Therefore, the system consumes more reactive power to raise the voltage level and improve the voltage stability condition in
the system. Voltage instability phenomenon could also be resulted from the contingencies caused by either line or generator outages apart from the stressed conditions of a power system network [13]. During contingency, the operating generators fail to operate and cause the reactive power supply by the generators suddenly drop in the system. Therefore, the system also has to improve the reactive power level to prevent voltage collapse in the system. Furthermore, power scheduling has also resulted in the change in power flow in the network and hence affects the system voltage profiles. Therefore, voltage stability in the system will be affected.

Voltage stability is important to maintain a secure power system operation. Therefore, an efficient voltage stability analysis technique is required in order to perform the voltage stability study accurately with less computational burden. Studies have shown that voltage stability can be improved by means of real and reactive power rescheduling in a power system [14 – 17]. Basically, real and reactive power planning could be controlled by reactive power dispatch, compensating capacitor placement, transformer tap changer setting and installation of FACTS devices. Hence, this research proposed a new technique for rescheduling the real and reactive power at voltage controlled buses and also identifying suitable location and sizing of compensating capacitors in order to improve voltage stability in power system and at the same time minimizing the total losses in the system under multi-contingencies.

This research also proposes a new approach for operating generator scheduling to be applied on reactive power control based on Evolutionary Programming optimization technique in power system. The proposed technique will determine the best combination of generator which should be dispatched with reactive power in the system based on SVSI, transmission loss and installation cost in order to improve voltage stability condition of a system. Two objective functions were considered separately for the OGS namely improving voltage stability condition indicated by reduction in SVSI and transmission loss minimization (TLM) in the system. The information obtained from this analysis allows the power system operators to schedule generator units in an economic way as required by the utility company.
In reactive power control (RPC) problem, many of the proposed methods for optimization focus on the constraints related to the steady state operations. Numerous optimization problems have more than one objective function in conflict with each other. It is very difficult to decide which section is most suitable for the objective function. Therefore, instead of single-objective function, this research has implemented the multi-objective into the system in order to solve the optimal RPC problem where trade-off between the different components of the objective function is fixed. It is important to develop a multi-objective optimization algorithm which take both voltage stability index and transmission loss into account, to provide users a set of options with flexibility to solve the problem. The presence of reactive power control into power system brings many benefits. If the goals of the research need more than one objective function to be optimized, then it is called multi-objective optimization problems. The genuine way of solving multi-objective problem is to consider all objective functions applied simultaneously. That is why this research has been implemented in multi-objective optimization in order to take all the objective functions into account.

1.2 OBJECTIVES OF STUDY

The objectives of this research are:

(i) To develop an algorithm for the identification of sensitive lines and generators, weak bus and secure in power system for constrained power planning analysis.
(ii) To develop a new and superior technique of power scheduling to improve voltage stability, minimize total transmission losses; and enhance of voltage profile for the system under stress and contingencies.
(iii) To develop a new and superior technique of FACTS devices installation in order to minimize total transmission losses and enhancement of voltage profile in the system under contingency (N-m) such as line outages and generator outages.
(iv) To develop an algorithm for operating generator scheduling identification in order to avoid hundred percent generator operations.

(v) To develop a multi-objective Evolutionary Programming algorithm to improve voltage stability, minimize total transmission losses for the system under stress and contingencies.

1.3 SCOPE OF WORK

Figure 1.1 shows the block diagram of overall activities conducted in this research. Initially, this work involved the implementation of SVSI for evaluating the voltage stability condition and optimization in power system for a system under stress and multi-contingencies. SVSI is used to evaluate contingency analysis and ranking for the line and generator outages. The results obtained from the line and generator outage contingency analysis and ranking were sorted in descending order to identify the line and generator outage severity in the system. Results from the contingency analysis and ranking are utilized in order to form the multi-contingencies selection to be applied in constrained power planning, constrained FACTS and multi-objective constrained reactive power control. In OGS, system with only stress condition is considered to be applied and tested. A stochastic optimization technique in the Evolutionary Computation hierarchy called the EP is applied in determining optimum CPP and FACTS to improve the voltage stability condition in the power system. Multi-objective optimizations namely MOEP and MOAIS are also considered for the combination of two objective functions namely VSI and TLM. SVSI is utilized as the fitness when VSI is taken as the objective function, while transmission loss is taken as the fitness when objective function is to minimize the transmission loss. The process was conducted at various loading condition in order to investigate the effects of loading condition and also to monitor the consistency of the process. For the purpose of validation, the propose techniques are tested on most IEEE Reliability Test System (RTS) namely IEEE 30-bus RTS and IEEE 118-bus RTS.
1. To develop algorithm for CPP analysis using SFS as indicator
   - To identify sensitive lines and generators
   - To identify weak and secure bus
   - Validation verification

2. To develop EP engines for power scheduling purpose considered multi-contingencies
   - Constrained Reactive Power Control (CRPC)
   - Constrained Active Power Scheduling (CAPS)
   - Constrained Hybrid Power Scheduling (CHPS)
   - Perform comparative studies

3. To develop EP engines for FACTS installation considered multi-contingencies
   - Constrained Static Voltage Controller (CSVC)
   - Constrained Thyristor Controlled Series Compensator (CTCSC)
   - Constrained Unified Power Flow Controller (CUPFC)
   - Perform comparative studies

4. To develop new approach for OGS
   - Based on RPC
   - Based on EP
   - Validation verification

5. To develop multi-objective programming engines considered multi-contingencies for CRPC
   - Multi-Objective Evolutionary Programming (MOEP)
   - Multi-Objective Artificial Immune System (MOAIS)
   - Perform comparative studies

Figure 1.1: Scope of Work diagram
1.4 SIGNIFICANCE OF THE STUDY

The significance of this study are:-

(i) The power scheduling research explored a new approach in optimizing the power control which will result in the improvement of voltage stability condition in a power system.

(ii) The proposed technique can be utilized by the power system engineers and operators in order to alleviate the problems related to voltage instability and hence reduce the incidence of voltage collapse especially in the event of contingencies

(iii) In operating generator scheduling, the proposed technique able to economize the usage of capacitor bank or of the reactive power support devices. This will help power system utility to get ideas in managing the reactive power support. In addition, the implementation of the technique can be utilized by the power system engineers and operators in order to identify the correct combination of generators operation and the power schedule in the power scheduling system hence will minimize the system operation cost.

1.5 ORGANIZATION OF THESIS

This thesis begins with some preliminary studies on the current scenarios of voltage stability analysis, contingencies analysis, power planning, FACTS, operating generator scheduling and multi-objective. Literature review on the work that has been carried related to voltage stability studies are presented in Chapter 2. This chapter describes several important terminologies related to voltage stability studies including voltage stability analysis techniques, voltage stability index, maximum loadability and contingency studies, power scheduling, FACTS devices as compensation tools, operating generators scheduling and multi-objective optimization techniques.