OPERATIONAL PLANNING OPTIMISATION IN SUBTRANSMISSION SYSTEMS USING EVOLUTIONARY ALGORITHMS

Danilo BELPIEDE
CPFL Energia – Brazil
dbelpiede@cpfl.com.br

Nelson KAGAN
University of São Paulo – Brazil
nelsonk@pea.usp.br

ABSTRACT

This paper deals with the operational planning of subtransmission systems in order to minimize the supplying costs in the bordering buses to the transmission system, such that the main technical criteria are met. This approach allows for the distribution company to comply in an efficient way to the competitive market by improving their day-to-day procedures. Active and reactive power flow optimisations are pursued in sequence.

The main control variables that are to be determined along the daily loading conditions existing in the Utility's Control Operation Center comprise the status (open or closed) of some network switches and the voltage taps of the supplying substations, that connect the transmission system to the subtransmission network. Also, the existing demand and energy contracts impose different unitary costs according to the supply site and the instant in time (peak or non-peak hours).

Evolutionary algorithms are applied in a sequenced way to determine the network configuration in a real transmission system. The transmission system is represented through the use of equivalent networks so that changes in the subtransmission system, e.g. the network configuration, are well propagated to the supplying system. The developed evolutionary algorithms show very promising results and motivate the authors for their implementation under on-line conditions.

INTRODUCTION

In order to respond to the demands of the regulatory agency and of the electricity market, the electric energy companies have constantly developed efforts in the direction to improve the quality of service regarding the supply of electric energy to its customers. In this context, the need to operate electrical power systems in the most efficient way is turning the operational planning into a more complex task.

In an electrical power system that contains a great amount of subtransmission lines, beyond many border points with the different transmission systems, a high number of viable operating alternatives makes the attainment of efficient or optimized solutions even more difficult. Moreover, depending on the yearnings of the company or the planner, one might contemplate multiple objectives in the search of these solutions, since these objectives possess different degrees of importance.

The operation planning of electrical power systems consists in a set of interventions to determine a global optimisation level of the system, as much as possible. Considering electrical subtransmission systems, the short/medium term operational planning consists in the attainment of the best operating system state in analysis, aiming to reach specific objectives, though keeping the external conditions of the supply system.

The proposed problem solution in this paper makes use of new intelligent systems techniques which have been increasingly applied, as it is the case of the Evolutionary Computation [1]. This resulted in the development of a methodology to deal with the power flow optimisation in electrical subtransmission power systems, by using two techniques: the Genetic Algorithms and the Evolution Strategies.

It is particularly intended to develop a methodology capable to assist the operational planning of electrical subtransmission systems, dealing with multiple bordering/supply points and diverse options for network configuration. The problem to be solved, therefore, consists in searching an operating system state that contemplates the optimisation of the defined short and medium term operational planning objectives.

DESCRIPTION AND PROBLEM FORMULATION

The operation of an electrical power system must meet technical constraints, basically the ones related to voltage levels and loading levels in lines and power transformers, since these parameters affect directly the quality of energy supply. Also, it must be possible to operate an electrical system in a way that technical losses are as low as possible, beyond the reliability aspects to guarantee the security in the supply of electric energy.

In a fairly simple way, within the scope of electrical subtransmission systems operational planning, the power flow optimisation problem can be described in the following form:

min (operational planning objectives)
subject to

- *Constraints due to bordering transformers capacity*
- *Constraints due to line capacity*
- *Constraints due to bus voltage levels*

The problem variables of the power flow optimisation in electrical subtransmission systems are related to the changes

in the operating system state. Thus, it can be affirmed that the control variables of the optimisation problem in electrical subtransmission systems are the switch device status (switches or breakers) and the bus voltage levels at the bordering points.
The power flow optimisation problem in subtransmission systems with multiple bordering supply points consists in determining a configuration that takes into account one or more objectives, such that some imposed technical constraints are met.
The proposed model considers some features, all of them compatible with the operational planning, namely:

- All consumer demands must be fully met;
- All existing loads must be connected, through an electric path, to at least a supply point;
- The electrical subtransmission networks can operate in radial or in meshed configurations;
- It is admitted that the strategic established switches can have their status modified;
- Investments in the network are not considered.

The injected active power flows to a electrical subtransmission system through the different bordering points are strongly influenced by the internal network system configuration, by the operating configuration of the transmission lines, by generation levels, power interchanges between geoelectrical regions and so forth. In such a way, the control of active power injected to the subtransmission system can be controlled by opening or closing some strategic subtransmission lines.
The solution of such active power flow optimisation problem in electrical subtransmission systems, where the best network configuration is seeked, can make use of different optimisation methods. However, this work intends to demonstrate the results from the application of a Genetic Algorithm [2,4] to the problem, since it has been successfully applied to several related problems.
The reactive power injected to an electrical subtransmission system is basically affected by the internal network configuration and by the voltage levels adjusted by tap changers in the bordering power transformers. Varying the voltage magnitude values along the bordering buses can definitely alter reactive power flows and consequently the operating system state.
As for such reactive power flow optimisation problem, the use of an appropriate method to tackle continuous variables becomes necessary. Many methods can be applied in this type of problems. Differently from Genetic Algorithms, Evolution Strategies [3] possess certain characteristics that favors it in dealing with continuous variables in optimisation problems.

EVOLUTIONARY ALGORITHMS

Evaluation Function

Evolutionary algorithms demand an evaluation function, which is composed by the objective function and contraints of the studied optimisation problem. A possibility for this function is to evaluate the alternatives in a gradual way according to improvements in the objective function or violations in the problem constraints. The most usual form to reach this is to decrease the evaluation function the more one determined solution transgresses the original restrictions of the problem. Frequently, the restrictions are incorporated to the evaluation function through penalty factors [4], which represent the original restrictions of the problem.
An important objective in operational planning of electrical subtransmission systems is the minimization of the transmission system duty power flow costs [5]. A possibility for the evaluation function is to use a relation between a reference value and the value of the transmission system duty cost of the configuration, represented by an evaluated alternative, in the form:

$$f_{eval,i} = \frac{C_{ref}}{C_i + \sum_{k=1}^{n_{restr}} r_k P_{i,k}} \qquad (1)$$

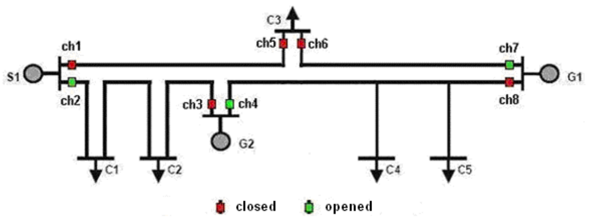
Where,
$f_{eval,i}$ = alternative i evaluation function
C_{ref} = reference value for the transmission system duty cost, in R$
$C_i = \sum_{j=1}^{n_{border}} T_{border,j} \cdot U_{border,j}$ = transmission system duty cost for the alternative i, in R$
$T_{border,j}$ = transmission system use tax in bordering point j, in R$/kW
$U_{border,j}$ = demand of the bordering point j, in kW
n_{border} = number of bordering points
$P_{i,k}$ = penalty factors applied to alternative i, constraint k
r_k = multiplying factors
n_{restr} = number of constraints

Penalty factors are applied to the main constraints of the problem, namely the overload of bordering power transformers, P_{FR}, the possible overloads in subtransmission lines, P_{TR}, and possible violations in system bus voltage levels, P_V.

ACTIVE POWER FLOW OPTIMISATION – APPLICATION OF A GENETIC ALGORITHM

In this work, the active power flow optimisation problem, i.e. the determination of the status of the system switches, is developed by a Genetic Algorithm (GA). An immediate alternative is to define the size of the GA string that represents an individual as equivalent to the amount of strategic switch elements in the network and associate one locus of the string to each component status. One easily notices that the control variables clearly assume the status 'closed' or 'opened' associated to the values '1' and '0', respectively.

Fig. 1 shows an electrical subtransmission network containing three connections *S1* (represented as a swing bus), *G1* and *G2* (represented as generation buses), five substations (*C1* to *C5*) and six switch devices (*ch1* to *ch6*) and the corresponding GA string which is codified according to the illustrated configuration.



1	0	1	0	1	1	0	1
b_7	b_6	b_5	b_4	b_3	b_2	b_1	b_0
ch_1	ch_2	ch_3	ch_4	ch_5	ch_6	ch_7	ch_8

Fig.1. An electrical subtransmission system representation and its switch codification as a GA individual

This type of codification does not guarantee that GA individuals correspond to feasible network configurations. Specially in large networks, where a high number of switches is expected, many individuals randomly generated in the initial GA population will correspond to unfeasible solutions (existence of disconnected load blocks).

To prevent the sprouting of individuals corresponding to unfeasible network configurations, a specific individual decoding procedure was developed in this work. Such decoding changes the values in the string bits, when they lead to unfeasible configurations. The decoding process considers each individual string, bit by bit, analyzing the resulting system state and each partial configuration. When necessary, some network switches have their status changed (open to closed, i.e. bit changes from 0 to 1) when some determined rules apply. The decoding process for electrical subtransmission systems is based on the concept of load blocks, which are connected through system switches. In such analysis, load blocks are imposed to be directly or indirectly connected to at least one supply point.

REACTIVE POWER FLOW OPTIMISATION – APPLICATION OF AN EVOLUTION STRATEGY

In this work, the reactive flow optimisation problem (determination of the power transformer taps) is developed by an Evolution Strategy.

Fig. 2 illustrates a generic electrical subtransmission system containing three connections with the Basic Transmission Network *S1*, *G1* and *G2* and three substations (*C1* to *C3*), and its corresponding representation through the codification of the individual.

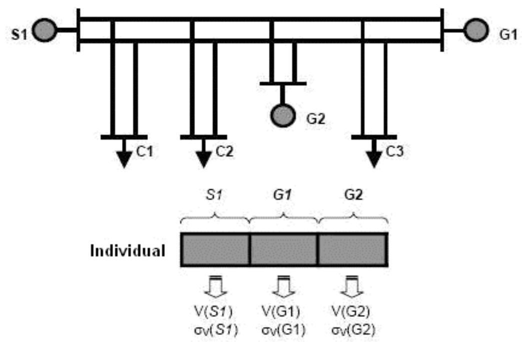


Fig.2. An electrical subtransmission system representation and its voltage bordering bus codification as an individual

The Evolution Strategy makes use of a population of individuals, which is randomly generated. The individuals of the population are evaluated according to the previous evalution function and evolve according to a number of operators (mutation, crossover, selection), leading to the optimal global solution after some generations.

APPLICATION OF THE OPTIMISATION MODELS

The active and reactive power flow optimisation models have been developed to operate in an independent and sequenced way. The active power flow optimisation gives a solution that represents a network configuration and corresponding status of each system switch. The reactive power flow optimisation works on this network configuration, i.e. the procedure relies on an initial active power optimisation .

In operational subtransmission planning studies, the supplying transmission system can be represented by means of external equivalents. The basic objective of the external equivalent is to simulate the reactions of the supplying transmission network when alterations in the subtransmission network occur.

The application takes into account a particular instant of the daily load. For the analysis and validation of the considered active and reactive power flow optimisation models, a part of a real system was selected, containing two bordering points and several operating configuration alternatives.

The transmission system duty costs for the two bordering supply points are $T_{border,1} = 0.087\ R\$/kW$ and $T_{border,2} = 1.523\ R\$/kW$.

The multiplying factors, r_{FR}, r_{TR} and r_V, applied to each penalty factor have been defined as unitary. Thus, all the constraints have the same degree of importance in the individuals evaluation.

Active Power Flow Optimisation

Five switch devices selected in the studied network represent the model control variables. The validation of the model is based on the analysis of the evaluation function by the simulation of all possible individuals to be generated and the comparison of the results with the application of the developed Genetic Algorithm. A standard operating condition was considered, i.e. the bus voltage levels at the bordering points set to 1 pu (per unit). The considered Genetic Algorithm simulation was developed with the following parameters: 10 generations; 50 individuals per population; 85% crossover probability and 1% mutation probability.

The GA evolution process converged to the same configuration simulated through the complete solution mapping. Fig. 3 illustrates the resulting network configuration.

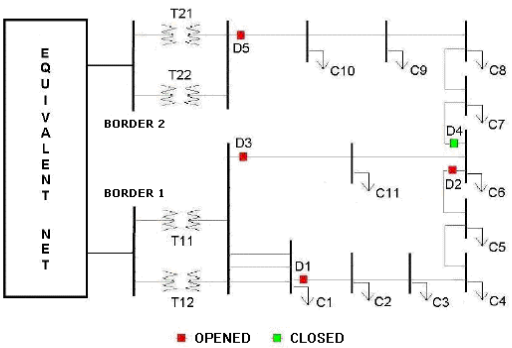


Fig.3. Optimisation problem solution for the active power flow

Reactive Power Flow Optimisation

According to the proposed methodology, the reactive power flow optimisation problem is applied over the resulting network configuration determined by the active power flow optimisation. However, for analysis and validation of the considered model, it is presented another case that contains the same subtransmission network though with an alternative operating condition in which the bordering points are connected in a ring configuration, what makes the problem a little bit more complex. The model validation proceeds in a similar form as in the active power flow optimisation. It is established that the voltage magnitude values in the two bordering buses can vary in an operative range between 1.000 pu and 1.030 pu. The mapped solution space cannot be given in a continuous form, so it is necessary to apply a discretization of the voltage values at the bordering buses. Varying in 0.030 pu discrete steps in the operating range, all the combinations are simulated and evaluated according to the proposed evaluation function.

The considered Evolution Strategy simulation was developed with the following parameters: 100 generations; 10 individuals per population; 10 mutations per individual; 50% crossover probability; 100% mutation probability and maximum age of the individuals equal to 5 generations.

The Evolution Strategy has verified the convergence of the process to the same solution as the one identified by the complete discrete solution mapping. Tab. 1 presents the values that define the operating configuration related to the reactive power flow optimisation.

Bordering Point	**Operation Voltage (*pu*)**
Border 1	1.009
Border 2	1.030

Tab.1. Optimisation solution for the reactive power flow

CONCLUSION

The results obtained concerning the operation planning optimisation in electrical subtransmission systems through Evolutionary Algorithms are very promising. Modeling improvements and new considerations regarding the evaluation function must be realized to represent the objectives of real problems and other needs of electrical utilites.

The proposed models quickly determine practical solutions to the active and reactive power flow optimisation problems. The obtained results show the efficacy of the developed algorithms in the search of desired solutions.

The methodology in this article assists the daily planning studies carried out in Control Operational Centers.

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