A REVIEW OF VOLTAGE/VAR CONTROL

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Abstract

This paper presents a survey of voltage/Var control techniques. It introduces both the control devices for individual reactive power sources and several popular control systems (OPRF, hierarchical voltage control, expert system and fuzzy logic) for whole power transmission network.

1. INTRODUCTION

During the daily operation, power systems may experience both over-voltage and under-voltage violations that can be overcome by voltage/Var control [1]. Through controlling the production, adsorption, and flow of reactive power at all levels in the system, voltage/Var control can maintain the voltage profile within acceptable limit and reduce the transmission losses. In the last 20 years, this problem has attracted the interest from both academia and industry and this has produced many special devices and algorithms. Some countries have adopted some of these in their real power networks and achieved reasonably successful results [2].

This paper first introduces reactive power sources and control devices for them. Secondly, it explains four significant control algorithms (Optimal Reactive Power Flow (OPRF), hierarchical voltage control, expert system and fuzzy logic) for whole power transmission network. These algorithms cover: rigorous mathematical solutions, smart artificial intelligence approaches, research projects and real applications. They reflect the state of the art of voltage/Var control.

2. REACTIVE POWER SOURCES AND THEIR CONTROL DEVICES

The controllable reactive power sources include generators, shunt reactors, shunt capacitors and On Load Tap Changers of transformers (OLTC).

Generators can generate or absorb reactive power depending on the excitation. When overexcited they supply the reactive power, and when underexcited they absorb reactive power. The automatic voltage regulators of generators can continually adjust the excitation [1].

Reactors, shunt capacitors and OLTC are traditionally switched on/off through circuit breakers on command from the operator. Since the early eighties, advances in Flexible AC Transmission Systems (FACTS) controllers in power systems have led to their application to improve voltage profiles of power networks. The most frequently used devices are: Reactive Power Controller (RPC) and Static Var Compensator (SVC).

The RPC connects or disconnects capacitor stages automatically by detecting the phase divergence between the fundamentals of current and voltage. The measured divergence is compared with several segmental set phase divergence regions, capacitor contactors will be switched on or off according to it.

Compared with RPC, the SVC is more advanced electronics equipment. It can provide continuous capacitive and inductive reactive supply to the power system. The SVC typically consists of a Thyristor Controlled Reactor (TCR), a Thyristor Switched Capacitor (TSC) and AC Filters (ACF). From the viewpoint of power system operation, an SVC is equivalent to a controllable reactor and a fixed capacitor as shown in Figure 1.

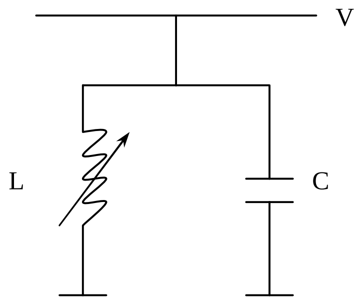

Figure 1. Equivalent SVC

Its output can vary depending on the level of generation and absorption of reactive power so as to maintain its terminal voltage at a certain level.

Both RPC and SVS incur large financial investment. Since they work only in a local area, the reactive power sources of a network must be coordinated with the aim to achieve network voltage stability.

3. OPTIMAL REACTIVE POWER FLOW

Similar to many other engineering problems, the complexity of the voltage/Var control problem led, from the beginning, to the use of mathematical methods. It is formulated as a constrained nonlinear optimization problem called Optimal Reactive Power Flow (OPRF):

$$\min f(x,u) \tag{1}$$

subject to

$$g(x,u) = 0 \tag{2}$$

$$x_{min} \leq x \leq x_{max} \tag{3}$$

$$u_{min} \leq u \leq u_{max} \tag{4}$$

$$h_{min} \leq h(x,u) \leq h_{max} \tag{5}$$

where the f(x,u) represents the goal for voltage/Var control and can include, for example, voltage variation around standard values and transmission losses. Constraints defined by equations (2) are the load flow equations to be satisfied at any operating point. Constraints defined by (3 – 4) are the minimum and maximum permissible control (u) (generator voltage, transformer's tap position and Var compensation) and state variable (x) (bus voltage magnitude and angle). Constraints defined by (5) are the security constraints that include the minimum and maximum permissible MVAR loading limits for generators, line loading limits etc.

A popular approach is the primal-dual log-barrier interior point algorithm [3]. It first transforms all inequality constraints into equalities by adding non-negative slack vectors, $s_i \geq 0$; secondly, The non-negativity conditions $s_i \geq 0$ are handled by incorporating them into logarithmic barrier terms; thirdly, the necessary Karush-Kuhn-Tucker (KKT) conditions of the Lagrange function of the equality constrained problem is formulated; finally, the nonlinear KKT system is approximated by a Newton's method. This interior point based method can deal with several thousand variables and achieve efficient convergence speed. Based on its results, the optimal reactive power control setting for current steady state can be decided. But the OPF can only reflect the steady state of power system. The high computation burden and a large number of controller movements make it less than an ideal tool for voltage/Var control.

4. HIERARCHICAL VOLTAGE CONTROL

Italy is one of the pioneers who have implemented automatic voltage regulation of the synchronous generators. Its approach is based on a hierarchical control structure (Figure 2)[4], which involves spatial and temporal decomposition of the whole control problem into several sub-problems.

Control Level	Tertiary	Secondary	Primary
Response time	Around 15 minutes or longer	One minute up to a few minutes	A few seconds up to one minute
Control area	Entire network	One zone	Single or a few unit

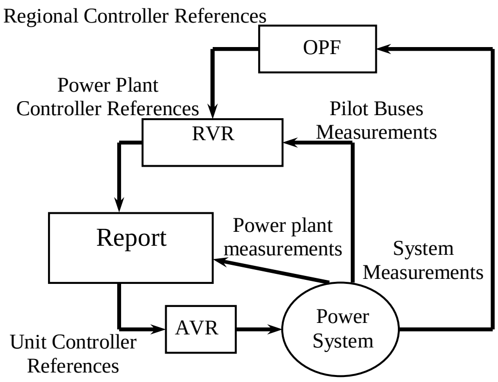

Figure 2. Hierarchical voltage control

The spatial decomposition follows the existing multi-level hierarchy of a power system, which divides the national network into areas around the pilot nodes. The behavior of the other nodes' voltage for normal perturbations follows the behavior of a pilot node's voltage in an area. The temporal decomposition is achieved by assigning a distinct response time to every level according to their complexities.

The National (Tertiary) Voltage Regulator (NVR or TVR) periodically receives (every 15 min.) the state of the power system. Then an Optimal Power Flow (OPF) computes the forecast optimal targets for the pilot node voltages based on current status and short-term load forecast. The set points are transmitted to the second hierarchical level that consists of the Regional Voltage Regulators (RVRs) and the power station reactive power regulators (REPORTs). After the RVR receives the set points of its pilot nodes, it decides the reactive power level for the REPORTs. According to this reactive power level, the REPORTs control power stations to deliver their reactive power proportionally to the reactive capability limits of the control units.

This approach have implemented in Romania, Italy, France, Spain, Belgium and some other countries. It is also the most mature automatic voltage/Var control system. It improves the voltage security by quickly bringing back the system voltages to normal values in a closed control loop after any contingency happened and continuously manage the reactive power generation based on the solution of OPF to keep a large enough margin for preventing voltage collapse. The transmission losses are also reduced by keeping the pilot nodes' voltages at their optimal values. This has another advantage of alleviating the operator's job and the operator can concentrate their efforts on the slow variation voltage/Var profile (e.g. daily peak to off-peak). But some limitations of this approach are:

- Coupling exists between some zones.
- Pilot nodes are difficult to decide.
- Too frequently control on generators
- Not considering the important effect of the other reactive power resources (capacitors etc.) together in real-time.
- It does not possess the capability to gain knowledge from experience.
- Analytical solutions cannot accurately reflect the nature of the stochastic power transmission system.

These disadvantages limit its wide application in real power networks.

5. ARTIFICIAL INTELLIGENCE BASED ALGORITHMS

Artificial Intelligence provides possible alternatives to overcome the limitations of the classical analytical methods [5].

Tan and Michael deployed an expert system on Tasmania power network in Australia in 1995 [6]. The expert system interacts with the power system analysis software providing analysis of the network sensitivity matrix and data for the knowledge base. They approach the problem in two steps:

- Solving the AC power flow for base case to identify the weakest area and the critical contingency, then constructing the "three tier" internal subsystem around weak area.
- The inference engine (Figure 3) of the expert system employ the empirical and heuristic rules saved in knowledge base and sensitivity matrix from network sensitivity analysis program to select the most effective control action.

The hybrid expert system's computational performance is improved significantly by reducing the size of power systems and eliminating the less effective voltage controllers. The embedded knowledge also enhances the accuracy over the classical sensitivity matrix method. But it can only perform the existing rules rigidly and had no insight to discover new knowledge. Also, it can only solve the current voltage violations and cannot deal with the dynamic stochastic nature of voltage/Var control problem.

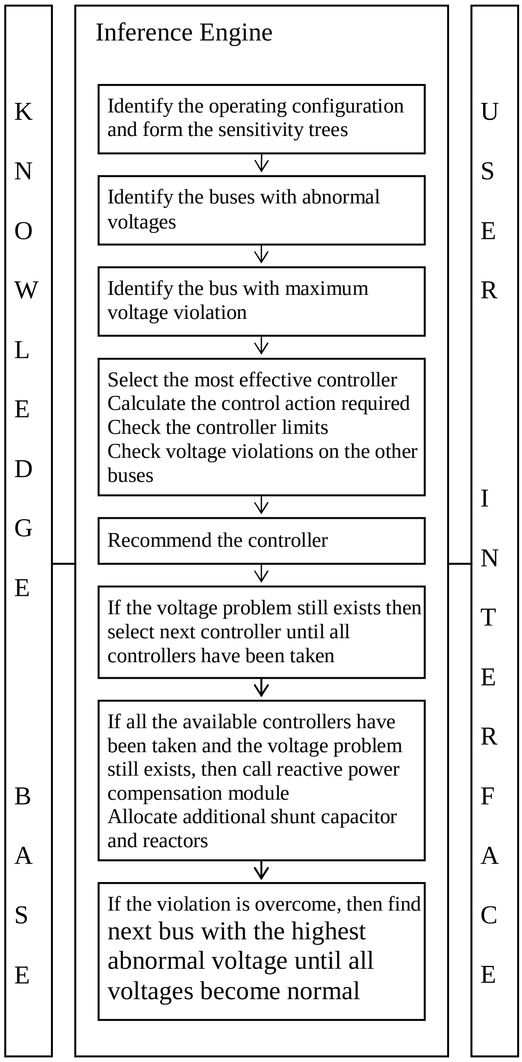

Figure 3. Expert system's search strategy

Fuzzy logic can deal with the uncertainties of real power system through fuzzy set theory. B. Venkatesh and G. Sadasivm combined fuzzy logic with successive linear programming to solve voltage/Var control problem [7]. After solving the base case power flow, the multiple objectives (economic and security) are formulated by a linear function with reactive power control variables. Every objective and constraint is expressed by a membership function that defines the degree of closeness to the optimum when it assumes a value. Then the objective functions are pushed as close as possible to their optimum values and the enforcement of constraints are maximized by maximizing the minimum of these membership functions. Theses steps are successively repeated until the improvement is small. Compared with the traditional successive linear programming, more satisfactory solution is found. But it only deals with steady state power system.

6. CONCLUSION

In this paper, several representative techniques of voltage/Var control are reviewed. Their advantages and disadvantages are analyzed. The future challenge is to how to efficiently and accurately solve the problem taking into consideration the dynamic nature of power systems.

7. REFERENCES

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