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Role of Voltage Stability and Frequency in Power System Operation & Control

Dr. Shekhappa G. Ankaliki*

Professor & PG Coordinator, Electrical & Electronics Engineering Department, SDM College of Engg. & Tech, Dharwad, Karnataka, India

Abstract – The basic operating requirement of a power system is that total generation must always be balanced to prevailing total consumption or load and maintaining acceptable levels of voltage and frequency. This paper presents role of voltage stability and power frequency in power system operation & control. It covers voltage collapse phenomena, prevention of voltage collapse, detection of vulnerable systems' state and load frequency control. Finally conclusions are drawn.

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1. INTRODUCTION

The main object of modern electricity utilities/electricity boards is to deliver electric power and energy to the consumers at minimum cost consistent with sound engineering practices and standards. The voltage stability problem is now a serious concern to the electric utility industry. Many large interconnected power systems are increasingly experiencing abnormally high or low voltages and voltage collapse. These voltage problems are associated with the increased loading of transmission lines, insufficient local reactive supply and transfer of power over long distances. The heart of the voltage stability problem is the voltage drop that occurs when the power system experiences a heavy load and one serious type of voltage instability is voltage collapse. Voltage collapse is characterized by an initial slow progressive decline in voltage magnitude of the power system buses and a final rapid decline in the voltage magnitude.

Voltage stability is defined as the ability of a system to maintain voltage such that an increase in load demand is met by an increase in power. The problem of voltage collapse may be simply explained by the inability of the power system to supply the reactive power or by an excessive absorption of reactive power by the system itself. It is to be understood as a reactive power problem and it is strongly affected by the load behavior (i.e. constant and for varying voltage).

The instability could be initiated by a wide variety of contingencies such as loss of transmission lines, reactive support or generation. These contingencies could be within their own systems or in neighboring system. Also some of the contingencies are aggravated by limitation of voltage control. Also, the excitation of generators must be continuously regulated to match the reactive power demand with reactive generation; otherwise the voltages at various system buses may go beyond the prescribed limits

2. BASIC CONCEPTS IN VOLTAGE COLLAPSE PHENOMENA

A voltage stability phenomenon is a dynamic phenomenon and can be studied using time domain stability simulations. However, system dynamics influencing voltage stability are usually slow. Therefore, many aspects of the problem can be effectively analyzed using static methods. The static analysis methods allow examination of a wide range of system operating conditions and if appropriately used, can provide much insight into the nature of the problem and identify the key contributing factors. Dynamic analysis on the other hand is useful in a detailed study of a specific voltage collapse situations, coordination of protection and controls and testing of remedial measures. Dynamic simulations also permit examination of, if and how the steady state equilibrium point is reached.

2.1 P-V Characteristics

To understand the basic concepts of voltage instability consider a sample power system consisting of a synchronous generator with a constant voltage E_S at the sending end, feeding a load (P + jQ) over a transmission line of impedance Z shown in Fig.1. For constant power factor of the complex load S = (P + jQ), the graph of V_R with P i. e., the change in receiving end voltage V_R for the changes in receiving end power P is shown in Fig. 2.

It may be observed from the graph that for each value of received power P, there exist two values of receiving end voltage $V_{R.}$ Obviously one of them is associated with a very low voltage and hence a very high current unstable region of (dV/dP) > 0 which is beyond the thermal limit of the transmission line. The second value of V_R corresponding to the stable region where ((dV/dP) < 0. It can be observed from the graph that even before reaching the thermal limit an increase in power demand at lower power factors will lead to voltage instability. This is explained by the fact that with the increase in line current the resulting series impedance drop in the line also increases and the voltage collapse will be rapid because (dv/dP) > 0 i.e., the system is operating in the unstable region

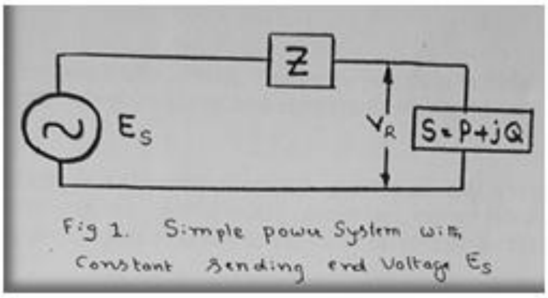

Fig 1. Simple power System with Constant Sending end Voltage Es

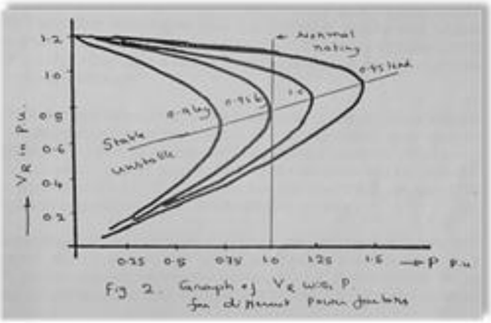

Fig 2. Graph of VR w.r.t. P for different Power factors

2.2 Q-V Characteristics

If the sending end voltage E_S and the load real power were fixed the graph of received MVARs Q, for increase in values of receiving end voltage V_R for the system shown in Fig.1 is illustrated in Fig.3. The graph has two distinctive stability regions. The right part of Q-V curve where (dQ/dV) > 0 corresponds to the stable region of operation and the left part of Q-V curve where (dQ/dV) < 0 corresponds to the unstable region. It can be observed from Fig.3 that below certain values of receiving end voltage for a particular load there is a rapid increase in reactive power consumption by the system and for extreme conditions i.e. (dQ/dV) tends to ∞ and the voltage will collapse. Based on the foregoing analysis voltage stability is defined as the ability of a power system to maintain voltage such that an increase in load demand is met by an increase in received power. A load demand here means switching in a load admittance which may result in an increase in power consumption. As the control and protective devices try to correct the situation (e.g. automatic tap changing, generator excitation limiting etc.,) voltage instability may lead to voltage collapse. The extent of voltage collapse of a given network depends largely on dynamic load characteristics.

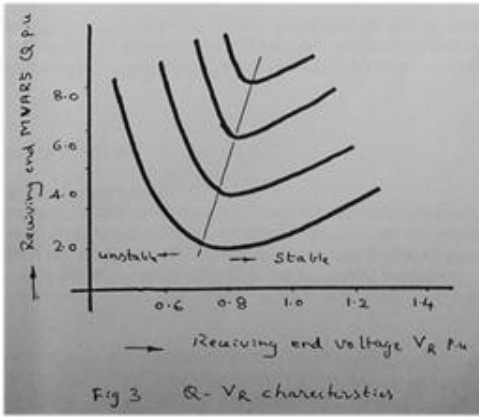

Fig 3 Q- VR characteristics

2.3 Prevention of Voltage Collapse

Planning Measures:

Voltage stability characteristics of a power system are significantly affected by reactive power source and their characteristics. Hence adequate voltage stability is assured by a proper design of location, size and capacity of reactive power sources.

a) It is necessary to provide AVRS to the generating units to compensate for line drops there by in effect move the point of constant voltage electrically close to the loads, thereby improving the voltage stability. In modern large interconnected systems, manual regulation is not feasible and therefore automatic generation and voltage regulation equipment is installed on each generators

b) Coordination of protection and controls: Simulations of typical system disturbances indicate lack of coordination between generator and power system requirement. Hence adequate coordination should be ensured.

c) Under voltage protection schemes will prevent widespread system collapse.

Operation Measures:

a) Stability Margin: System should be operated with adequate voltage stability margin by appropriate scheduling of reactive power sources and voltage profile. If the required margin is not available with the existing reactive power sources it is necessary to limit power transfer and add new units to provide voltage support at critical areas.

b) Spinning Reserve: Adequate spinning reserve should be ensured by operating generators.

c) Operator's action: Operators must be able to recognize voltage stability related symptoms and initiate appropriate actions such as power transfer, voltage control and as a last resort load shedding may be necessary in order it prevent system collapse. Online identification of potential nodes of voltage instability followed by remedial measures would be invaluable in this regard.

2.4 Voltage Collapse Protection Scheme

The following some of the schemes have been used in the power system

i) Auto load rejection

ii) Automatic switching of shunt capacitors/ shunt compensation

iii) Automatic blocking of on load tap changer

Fast auto reclosure (0.9 s to 1.3 s) is used as a first measure to maintain voltage within acceptable limits. If reclosure is successful voltage recovers and system returns to normal. If reclosure is unsuccessful depending on how the voltage drops, load rejection may be initiated followed by capacitor switching and possible LTC blocking

3. DETECTION OF VULNERABLE SYSTEM STATE

Referring to the sample two bus system shown in Fig.1, an index called voltage stability index defined as

$L_1 = |S/Y_{11}*V_R^2|$

Where Y_{11} is the complex self-admittance at load bus.

The range of L is $0 \leq L \leq 1$

This concept of voltage instability index can be extended to a multi-node power system where in the index for any node j can be computed as

$L_j = |S_j/Y_{jj}*V_j^2|$

And the global indicator L describing the stability of the complete system is given by

$L = \text{Max}\ |L_j|$

$j = N$

It is important to note that voltage stability is guaranteed only if $L < 1$

Interpretation: The indicator L is a quantitative measure of the system to the stability limit. Thus index L_j indicates those nodes from which a voltage collapse may originate once the numerical value of L exceeds the limit.

4. CONTROL OF POWER AND FREQUENCY

As frequency of the system is dependent on the speed of the generator it is desired that under steady state, machine runs at normal speed so that it delivers power at rated frequency. This object of maintaining frequency or in other words speed of the generator constant is achieved by the *speed governor.*

Both active and reactive power demands are never steady and they continually change with the rising or falling trend. Steam input to turbo-generators (or water input to hydro-generators) must, therefore be continuously regulated to match the active power demand, failing which the machine speed will vary with consequent change in frequency which may be highly undesirable. Change in frequency causes change in speed of the consumer plant affecting production processes. Further, it is necessary to maintain network frequency constant so that the power stations run satisfactorily in parallel, the various motors operating on the system run at the desired speed, correct time is obtained from synchronous clocks in the system and the entertaining devices function properly. Maximum permissible change in power frequency is ± 3%

For small changes active power is dependent on internal machine angle δ and is independent of bus voltage while bus voltage is dependent on machine excitation (Therefore on reactive generation Q) and is independent of machine angle δ. Change in angle δ is caused by momentary change in generator speed. Therefore, load frequency and excitation voltage controls are non-interactive for small changes and can be modelled and analyzed independently. Furthermore, excitation voltage control is fast acting in which the major time constant encountered is that of the generator field; while the power frequency control is slow acting with major time constant encountered is that of the generator field; while the power frequency control is slow acting with major time constant contributed by the turbine and generator moment of inertia this time constant is much larger than that of the generator field. Thus, the transient in excitation voltage control vanish much faster and do not affect the dynamics of power frequency control.

4.1 Electrical load Characteristics

The power demand of various equipment would considerably different from that of the rated conditions under various operating conditions. In case of transformers, reduction of frequency reduces the core loses. In case of induction motors the speed variation is directly proportional to frequency and the pull-out torque is inversely proportional to the square of frequency. Similarly, low voltage reduces the power requirement in case of resistance loads such as lighting, refrigerators, air-conditioning etc.

The frequency versus load characteristics of power system is therefore a drooping characteristic, that is the connected load decreases as the frequency decreases and it is in the order of 0.5% per 0.1 cycles. For example if the frequency decreases by 0.1 cycles in a system of load 2000 MW, the automatic decrease of the connected system load would be 10 MW simultaneously.

4.2 Generation Characteristics

The generation versus frequency characteristics is determined by the speed-droop setting on the generators. The generation characteristics is an increasing characteristics of 0.5% per 0.1 cycles drop in frequency. For example if the frequency decreases by 0.1 cycles in a power system load of 2000 MW, the automatic increase in generation would be 10 MW.

4.3 Natural Governing Characteristic

The natural governing characteristics of the power system is combination of the generation characteristics and the load characteristics added together. The combined natural characteristics would therefore be 1% per 0.1 cycles (0.5% load characteristics plus 0.5% generation characteristics).Thus the load added to the system is taken care of, instantaneously at a reduced frequency partly by the increase in generation and partly by the decrease in the connected load itself. If 20 MW of additional load come on the system of load 2000 MW (taken as an example earlier) operating at 50 cycles, the system would stabilize at 49.9 cycles with 10 MW drop in effective load and 10 MW increase in generation (0.5% of 2000 MW) under the natural response of governors guided by the natural governing characteristics.

4.4 Additional Regulating Controls

The frequency of the power system referred to in the example taken above, would be brought back to 50 cycles by increasing the required generation (if the generation capacity is available) by operating the speed-load control manually by the operator or automatically by the load frequency controller.

4.5 Load Shedding and Low/High Frequency Operation

a) **Load shedding:** Due to sudden loss of generation or addition of load, the system frequency initially falls down. If the spinning reserve in the system is adequate the power system frequency is slowly restored to normal automatically by the governors. Otherwise, increasing generation or load shedding to the extent required is effected to bring back the frequency to normal 50 cycles. If the available generation capacity is inadequate to meet the load left un-disconnected, the frequency continues to fall. Nuclear generating units or steam turbine units will have to be isolated from the system, when the reduction in frequency is considerable in order to avoid damage to turbine blades and other problems.

b) **Low/High Frequency Operation:** operation of the power system at slightly low frequency is resorted to when the generation capacity is inadequate to meet the demand to a certain extent by making use of the drooping characteristics of the load. On similar consideration, operation of the power system at slightly higher frequency is also resorted to, when the generation capacity (when Hydro Reservoirs are spilling) is higher than the load demand to certain extent. However this flexibility should not overshoot the limits of frequency discipline which is required to be maintained on many other considerations

c) The first large dip of frequency for load shedding must be slightly above the setting of under frequency relay (with rate of fall time delay unit) used for thermal and nuclear generating units. Other short term solutions adopted under critical power shortage conditioned subject to certain limitations are unscheduled load shedding operating the system at very low voltage and receiving stations on separate systems with split buses etc.

d) A satisfactory condition of operating power systems under a narrow band of frequency is a must for adoption of on-line load-frequency controllers and modernizing of interconnected power system operation. Further, the interconnection of electric power system through high voltage tie lines often dictate accurate frequency control as an adjunct in controlling load swings on the equipment and tie lines and regularization of the transfer of power between one system and the other.

5. ROLE OF POWER ENGINEER

In addition to the role of voltage and frequency in power system operation, the role of power engineers is therefore more important as they have to constantly balance the load with generation keeping in view the continuity, quality and reliability of electric service to consumers round the clock, even though the system load is continuously changing in a manner which is not entirely predictable and the in-service faults, failures of generators and system components are not totally avoidable.

6. CONCLUSIONS

The basic operating requirement of a power system is that total generation must always be balanced to prevailing total consumption or load and maintaining acceptable levels of voltage and frequency. The attainment of the desired objectives of delivering electric power and energy to the ultimate consumers at minimum cost consistent with sound engineering practice and standards call for adequate resources, proper planning, systematic development of power system based on system studies, modernization, sophistication and engagement of trained personnel to handle the system.

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Corresponding Author

Dr. Shekhappa G. Ankaliki*

Professor & PG Coordinator, Electrical & Electronics Engineering Department, SDM College of Engg. & Tech, Dharwad, Karnataka, India

E-Mail – sgasdmee@rediffmail.com