Applicability of Distributed Controllers for Reliable Operation of Interconnected Power Systems

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Abstract— Today as the load demand increases, there increases a need to strengthen system to fulfill the load requirement reliably. To overcome such requirements, today's systems have become more and more complex in nature. As of today we are able to design large systems to fulfill our requirements, but there are some draw backs to this system also. As the system complexity increases, the necessity of better system control is also required. There must be some sub system designed to control such a heavily stressed system. Here comes the need of automation adoption to the large Power Systems. This is very much important as the system reliability and availability has become severe parameters looking to the criticality of need of power for today's fast growing fields. In such a heavily stressed system, there are plenty of chances to occur disturbances. Much of these are transient in nature. If these transient disturbances are not taken care of, then there are chances to lead to collapse of whole system. Here one of such methods is described to overcome such transient disturbance which directly affects the Power System Stability of any system.

Key words: UVLS (Under voltage Load Shedding), SPS (System Protection Scheme)

I. INTRODUCTION

In the presented article an attempt has been made to develop a technique for maintaining constant voltage level for a reliable operation of interconnected power system. Modern interconnected power systems have grown in size and complexity in order to satisfy the increasing load demand. Initially the interconnections were means for supporting neighboring power systems in case of emergencies and sharing the responsibility for the frequency regulation in normal operation, thus reducing the burden and expenses of each participant. As the generation in one power system tended to be less expensive than in another system, or the load centers were closer to the neighboring power system generation, interchange transactions were established, providing for these long-term contracts. As a result, the tie-lines have become internal lines to the entire interconnected grid and are an indispensable part of the entire load supply process. Altogether, interconnections make economical use of the generated power and generally improve the overall reliability of the interconnected systems. Each power system, part of an interconnection, is designed to withstand pre-defined disturbances. To this purpose, all power system components are equipped with dedicated protection schemes, some system protection schemes designed to maintain stability are implemented, and system operators are trained to take measures in order to restore the system to normal conditions following a disturbance.

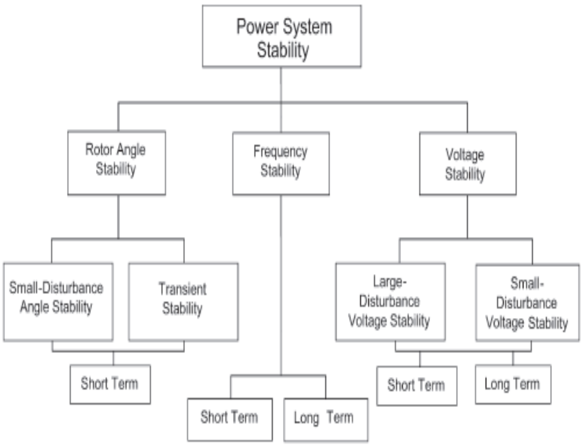

Fig. 1: Classification of Power System Stability

In these conditions, if the designed protection/control systems fail to maintain stability in one of the interconnected power systems, the whole interconnection becomes vulnerable. In such a case, the disturbance could spread in cascade over large distances and affect other power systems than the one where the initial disturbance took place. Major wide-spread events are rare, but their impact is important. Very often these outages result in a condition where some areas of a system separate from the rest of the system causing power imbalances in the so created islands. If an imbalance is not quickly contained this can lead to further loss of generation and transmission resources, and in the end to total blackout.

II. VOLTAGE STABILITY

A power system at a given operating state and subjected to a given disturbance is voltage stable if voltages near loads approach post disturbance equilibrium values. The disturbed state is within the region of attraction of the stable post disturbance equilibrium. Voltage has always been considered as an integral part of the power system response and is an important aspect of system stability and security. Thus, voltage instability and collapse can not be separated from the general problem of stability. However, in the recent years, the analysis of voltage stability has assumed importance, mainly due to several documented incidents in France, Japan, Belgium and Florida. There are several factors which contribute to voltage collapse such as increased loading on transmission lines, reactive power constraints, on-load tap changers (OLTC) dynamics and load characteristics. In contrast to voltage stability, the problem of loss of synchronism due to uncontrolled generator rotor swings is termed as angle stability. Loss of synchronism may also be accompanied by voltage instability. However, in the present context, voltage instability implies uncontrolled decrease in voltage triggered by a disturbance, leading to voltage collapse and is preliminary caused by dynamics connected by the load. Although the frequency may increase in voltage collapse, the generators normally remain in synchronism. The problem of voltage stability has received considerable attention in recent years. These are several aspects of the problems related to voltage profile in a system and it is important to distinguish them to avoid confusion. It is sometimes also termed as load stability. The terms voltage instability and voltage collapse are often used interchangeably. It is to be understood that voltage stability is a subset of overall power system stability and is a dynamic problem. The voltage instability generally results in monocronically (or aperiodically) decreasing voltages. Sometimes the voltage instability may manifest as undamped (or negatively damped) voltage oscillations prior to voltage collapse. control have to be selected properly to have maximum benefits. The SVC and STATCOM provide fast control and help improve system stability. The design of suitable protective measures in the event of voltage instability is also necessary. The application of under voltage load shedding controlled system separation and adaptive or intelligent control are steps in this direction. In this work, one of the powerful tools for the voltage stability improvement – undervoltage load shedding is used. Here efforts are made to design a SPS in which the voltage profile is maintained at constant level by the use of undervoltage load shedding phenomena. By using distributed controller the voltages can be maintained at some distinct levels. Thus in this work the design of load shedding controller is involved. Then the result of load shedding is achieved to justify the system working and reliability.

III. INTRODUCTION TO UNDER VOLTAGE LOAD SHADDING

A voltage collapse of part of the electrical system is an indication that for the existing conditions and contingencies, some portion of the combined generation and transmission system has been operated beyond its capability. Voltage collapse can also be a symptom of a much larger problem, and when the system starts to collapse, there is a real danger that the localized problem will cascade into wider areas. The purpose of proper system planning and operating philosophies is for the system to function reliably, and failing that, to contain the impacts of disturbances to localized areas. While UVLS is not mandatory for member systems, it can be useful tool to protect the system from voltage collapse, or uncontrolled loss of load or cascading. Voltage collapse, or uncontrolled loss of load or cascading may occur, for example, when sending sources are far enough removed from an area that the voltage at its loads experience a significant drop, especially during outage contingencies. System studies are needed to determine which systems are the potential candidates for a suitable UVLS scheme. It is most useful in a slow-decaying voltage system with the under-voltage relay time delay settings typically between 3 to 10 seconds. When overloads occur on long transmission lines in conjunction with a significant local voltage dip, then the effect of UVLS action would also be to alleviate such overloads.

IV. UVLS FOR PLANNING STANDARDS AND RELIABILITY CRITEAREA

UVLS is a powerful tool for planning the standards and other reliability criteria for the system. For this the system study is very much needed. Following points will cover how UVLS is useful for planning standards and reliability criteria

1) If UVLS is to be evaluated as an option to meet the planning standards and reliability criteria, load shedding studies should be performed as described in this report. Note that UVLS is not effective for those systems or contingencies where voltage collapse occurs in less than one second, or where overloads occur without sufficient voltage drop.
2) Systems that currently have a manual UVLS schemes could significantly improve system reliability by supplementing or replacing their manual schemes with automatic UVLS. The voltage pick-up and time delay settings of the automatic UVLS must be properly coordinated with the manual scheme.
3) Systems where voltage collapse is not likely to cascade into neighboring areas can still benefit from a cost-effective UVLS; 1) to avoid local voltage collapse, 2) to control loss of load, and 3) to facilitate load restoration.
4) Systems where the needed generation and /or transmission projects have been delayed, and the resulting lack of voltage support is likely to put the system at a risk of voltage collapse, could employ UVLS until those projects are operational.
5) Some systems may use UVLS to support an increase in transfer capability across a certain transmission path. If UVLS is used to meet the WSCC criteria in supporting a path rating, the failure of elements in the UVLS scheme should be considered in establishing the path rating.
6) If UVLS is used to meet planning standards and reliability criteria, then it must be highly reliable. UVLS is usually applied with local relays tripping local loads, in which case a failure to trip does not mean the failure of all UVLS, but only one portion of the UVLS. If the desired planning standards and reliability criteria, are not met with failure to trip the most effective load, sufficient additional load can be armed to shed so that the criteria would be meeting. Where a central UVLS or a direct trip control is used, redundancy may be necessary so that RAS failure is not credible.
7) UVLS should be designed in a way to recover adequate real and reactive power reserve margins in the system following contingencies. These margins should be equal to or greater than those defined under the WSCC Voltage Stability criteria.
8) Some individual systems or "pockets" within these systems may use UVLS to mitigate low voltage conditions caused by extreme weather conditions or unanticipated load growth, even without any disturbances. Such systems would need to drop even more load under contingencies. A multi-stage load dropping scheme may be suitable for such systems.

9) UVLS can be armed to operate during limited times or seasons of the year, for specific load levels, and /or during specific disturbances such as loss of a certain transmission path. This is in contrast to UVLS applied as a Safety Net where it is usually more appropriate to arm the scheme all the time.

V. OVERALL PRINCIPLE OF UVLS

The general principle which is described in this section enlights the philosophy of the scheme. The overall principle given here is to be implemented in a heavily stressed power system. The implementation of the system covers the following topics. The proposed scheme relies on a set of controllers distributed over the region prone to voltage instability. Each controller monitors the voltage V at a transmission bus and acts on a set of loads located at distribution level and having in°uence on. A sub transmission network may exist in between the monitored and the controlled buses, as sketched in Figure 2 Note that not all transmission buses need to be monitored and not all loads need be controlled. It is to be noted that the SPS is to be implemented to the area which is more prone to voltage instability and having more severity of faults. In this area, as an implementation of SPS, two controllers namely C1 and C2 are placed at two different buses or both at a single bus depending on the system design requirements. These two controllers sense the voltage in that region which they are placed and depending upon that voltage measurement, they shed the load to improve the voltage profile. Note that one controller should act upon the area in which it is proposed to act; else it has to remain idle for the voltage collapse of other areas or buses.

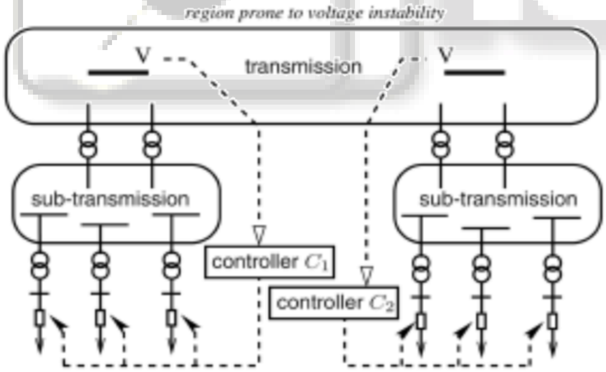

Fig. 2: Overall Principle of UVLS

From the overall principle of the SPS, we can explain the working of an individual controller. The main aspects of an controller are, to measure the voltage continuously and shed required load as per the design of the system in a predetermine appropriate time. After the shedding of a required load, the voltages are again sensed and matched with the threshold value to see the effect of the shedding. If the voltage profile is not improved over the threshold voltage, then more load is to be shedded. Thus this action of an individual controller works as a cyclic logical manner. Thus the controller works to maintain the voltage profile to some set level and thus to maintain the overall voltage stability of a system. Thus we can say that, the controller saves the system from voltage collapse which could arise due to system contingencies like faults or other. This also implies to all the controllers working in a group in large systems. They should work in co operation for overall system reliability. The individual design parameter settings are also liable to all the controllers working in the system. And place, time and amount criteria are also applicable to all the controllers. Thus the overall system needs to be developed to male all the controllers work in a systematic manner to cope up with any severe contingency arrived in the system. Now apart from all that theory part, we need to develop a real system study to justify the working of the proposed SPS. This chapter is dedicated to this work.

VI. TEST PROCEDURE

Now we are going to test the proposed SPS for the IEEE 30 bus standard test system. All the data of this system is standardize and available for the use. This data we will be using to develop the protection philosophy of our SPS. We study the system parameters and perform load flow test to the IEEE 30 bus standard system. Then this voltage levels are used for the development of the SPS. The main work involved for completing the task will be

- Selection of the zones of protection.
- Assigning the controller to the each zone.
- Thus ultimately we get the controller location.
- Selection of threshold voltage i.e. Vth for the system.
- Selection of various SPS parameters like, C, K for the system.
- Simulation of the system for the results of various parameters.
- The results evaluation.

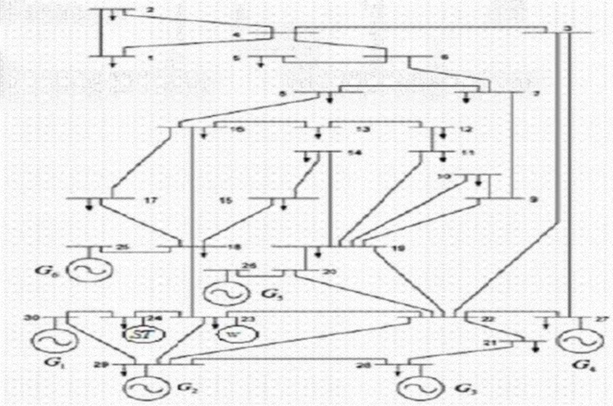

Fig. 3: IEEE-30 Bus System

Now we are dealing with the test procedure we have followed to implement the proposed SPS for the IEEE 30 bus standard system. The section mainly covers the implementation steps and the results which we have come to in brief. As stated in the above sections, we have divided the whole 30 bus system in to dedicated seven zones. Though the system is connected but we have done so to apply the system for all seven buses. Then the next step is to assign the controllers to each zone. Thus we have selected seven controllers which are assigned to seven zones. Thus the each controller has to sense the voltage for its zone and take the action as per the requirement of the SPS. The operation of each controller should be restricted to its zone only. Parameters of the controller are selected. For the testing of the SPS for this system, we have used the MatLab software. In this software all simulations are done to implement the

SPS for the given standard system. The controller working we have justified only with system contingencies. So we need to create contingencies artificially. By doing so, we can see how our SPS behaves when subjected to this type of system disturbances.

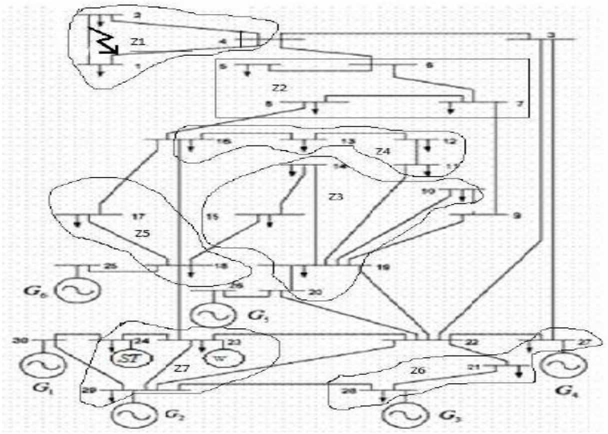

Fig. 4: Zone 1 Subjected To Disturbance

$Sr.No.$	V_{th}	$C(pu.s)$	$K(MW/pu)$	$\tau(sec)$	$\Delta P_{sh}(MW)$
C1	0.95	0.7	900	3.99	22.44
C2	0.95	0.7	900	4.9	19.11
C4	0.95	0.7	900	5.91	18.44
C3	0.95	0.7	900	5.58	17.04
C5	0.95	0.7	900	6.12	14.24
C7	0.95	0.7	900	6.98	11.18
C6	0.95	0.7	900	7.31	08.23

Table 1: Results of Controller Operation for R1

$Sr.No.$	V_{th}	$C(pu.s)$	$K(MW/pu)$	$\tau(sec)$	$\Delta P_{sh}(MW)$
C1	0.91	1.4	1500	3.2	72.56
C2	0.91	1.4	1500	4.3	63.23
C4	0.91	1.4	1500	4.7	51.32
C3	0.91	1.4	1500	4.5	48.88
C5	0.91	1.4	1500	4.3	41.28
C7	0.91	1.4	1500	4.9	35.55
C6	0.91	1.4	1500	5.23	29.12

Table 2: Results of Controller Operation for R2

The higher threshold value selection of the SPS, the load shedding required is minimum. But the time taken in the controller delay action will be more. So the system is first waiting for that if it is a some minor disturbance then the protective relays can operate an the voltage can be recovered. Thus this fact restricts the undesirable shedding of the load. As we keep the threshold value of voltage lower, the controller is acting much faster than earlier but the load shedding is also more. In this rule the controller is working faster because if it delays for somewhat more time then there are chances of the total system collapse due to this much higher voltage dip. To avoid this, controller action is much faster than the first rule. Thus this we can conclude that with higher Vth, controller takes more time to operate but sheds minimum amount of load. And with lower Vth, the controller acts much rapidly but then it has to shed more and more load to regain the system in its stable condition to maintain overall voltage stability of the system.

$Sr.No.$	V_{th}	$C(pu.s)$	$K(MW/pu)$	$\tau(sec)$	$\Delta P_{sh}(MW)$
C1	0.89	2.2	2300	3.23	80.29
C2	0.89	2.2	2300	3.4	77.26
C4	0.89	2.2	2300	3.2	74.04
C3	0.89	2.2	2300	2.5	73.21
C5	0.89	2.2	2300	3.8	70.88
C7	0.89	2.2	2300	4.2	57.24
C6	0.89	2.2	2300	4.7	48.40

Table 3: Results of Controller Operation For R3

$Rule$	V_{th}	$Time(sec)$	$LoadShedded(MW)$
R1	0.95	08	150
R2	0.91	06	350
R3	0.89	05	480

Table 4: Summary of Controller Operation

VII. CONCLUSIONS

We have seen the procedure of implementation of the SPS to standard IEEE - 30 bus system.

The design procedure and the guidelines for selection of parameters is the major concern for the engineers to define.

If necessary and corrective actions are taken, then the SPS robustness and reliability will increase superbly.

From all above considerations and implementations of the SPS into the actual system we have come across some conclusions from presented work. The first and foremost advantage of the system is its easy design considerations. There are very few steps to follow and not much complex considerations required for designing the system.

The major advantage of the system is the ability to protect a large system. The system design simplicity does not change with the size of the power system in which the SPS is applied for protection. The SPS can deal easily with large systems. For this, there are some design requirements which can be easily coped up.

The SPS proposed here, has tendency to monitor the voltage continuously. And according to that, the SPS controllers will take action against the voltage dip. This characteristic of the SPS will help us in the improvement of the voltage profile for any given large, small or medium system. The voltage level of the system is measured and corrected every time so there are less possibilities of voltage collapse. This will improve the power system stability.

The cascading of the system due to voltage collapse can be easily avoided by this type of SPS designing. The system designing is also flexible. The flexibility of the SPS is in the sense that the system can be designed for different types of lines. That means the SPS can be implemented for highly damped line or any other type of line. Just we have to follow the guidelines for the selection of the parameters of SPS. If proper care has been taken in selection of the best suitable parameters and system designing, then the SPS can give its best performance in any type of the line. In most of the cases, the proposed SPS is not used as a primary protection to the voltage dips. That means that we are primarily uses the relay and all those kind of protection philosophy for the fault detection and fault clearing. So that the voltage dips of the system can be immediately recovered. So the SPS proposed here is used as a secondary protection.

If the general protection of the line fails to recover that voltage dip, then the proposed SPS can work for the clearing of the fault. So for any sudden fault which is beyond the reach of the standard protection scheme, we need to go for load shedding through the proposed SPS to recover the voltage profile or to resist the voltage profile reduction beyond the threshold voltage limit. Thus if the primary protection recovers the system voltage by clearing some minor faults then there is no need to shed the load. Thus this will help us to avoid the unnecessary load shedding.

To improve the steady state and transient stability of the system it is very much advisable to go for the voltage profile monitoring and improvement. This tool will help us to reduce the chances of the voltage collapse and to have better system availability.

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