Wide Area Protection (WAP)

A Strategy to Counteract Large Area Disturbances

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1 Introduction

In view of the increasing probability for outages due to the system overloads, which are caused by the ever-increasing demand for electric power, utilities are examining what modern information technology can contribute to improve this situation. Our proposal to review the present protection strategy to counteract large area disturbances addresses the potentials that are derived from the advances in system operational, protection and control techniques. It will be explained how the application of numerical technology can avoid catastrophic disturbances to occur or at least to keep the impact of single fault within certain limits.

2 Review of Experiences with Large Area Disturbances

Extensive literature is available on disturbances that have occurred throughout the world. While the initial incidents, which have triggered the disturbances, varied the results were one ore more of the following:

- Frequency instability
- Voltage instability
- Cascade tripping due to overloading

These issues are briefly reviewed in order to suggest a solution to counteract the impacts of these phenomena.

2.1 Frequency Instability

Frequency instability usually arises following the tripping of generators or heavily loaded transmission lines. Transient or angular instability is very often a precursor to frequency decline in a power system.

2.2 Voltage Instability

Voltage instability occurs when heavy system loading creates large reactive power demands that result in an excessive voltage gradient between generation sources and load centres.

2.3 Cascade Tripping

Cascade tripping typically commences when tripping of a transmission circuit, due to the operation of a protective relay, causes overloading of the remaining circuits.

Cascade tripping of generators usually occurs during a voltage decline on the system when, in attempting to increase reactive power output, field current limiters operate to trip the unit leading to a rapid deteriorating voltage profile followed by similar tripping of remaining generators.

3 Review of Strategies for Protection and Control

In contrast to the requirements for protection relays designed to protect individual plant objects, system protection schemes intended to prevent voltage or frequency instabilities have to cope with the loss of generation on a large scale and/or loss of one or more transmission lines. Information technology offers digital applications, in terms of numerical adaptive protection relays, integrated disturbance recorders and fast broadband communication much greater functionality and overall efficiencies than conventional analogue techniques.

In preventing or counteracting disturbances the following prerequisites are essential for the control and protection scheme:

- A predetermined preventive and restoration strategy for the opening of lines in order to achieve optimal islanding
- Load shedding to counteract frequency or voltage decline
- Voltage support measures

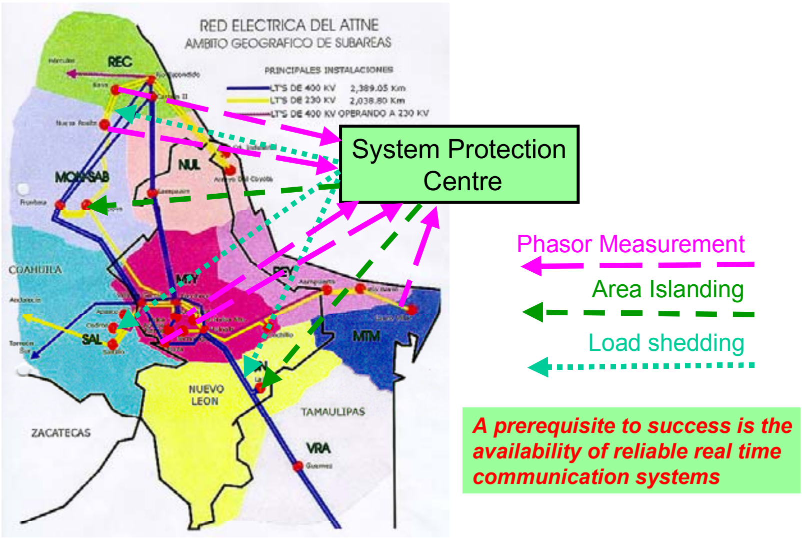
3.1 Protection against Frequency Instability

Today, in conventional technology protection against transient or angular instability is provided by means of high-speed auto-reclosure following line fault clearance. This is, however a crude trial-error method, which bears the risk of causing significant additional damages in cases where reclosure is conducted onto faults or in the close vicinity of power plants. With numerical technology this function can be improved by means of adaptive recloser schemes, which avoid reclosure onto faults.

Power swing tripping relays are sometimes applied to detect the onset of frequency instabilities. In conventional technology it is difficult to make them to respond correctly and fast enough. A further requirement for successful operation is that the relays, when operating, ensure that the power system is sectionalised into predetermined number of sectors. However, the heavily meshed nature of modern networks makes this a very difficult task as large areas may be affected by the instability. This is the reason why power swing relays as traditionally applied are not in the position to reliably protect the power system against frequency instabilities.

In order to prevent escalation in frequency instability it is necessary to have information available on the system conditions in terms of voltage and current phasor measurements from both local and remote locations. Apart from this, one has to have the possibility to adapt the concerned relay behaviour according to a defence plan, i.e. which circuit breaker is to block or to trip to provide optimal islanding.

This requires the application of adaptive line protection relays at key points throughout the network and a central co-ordinating function as outlined below. A prerequisite to success is the availability of reliable communication systems.



A prerequisite to success is the availability of reliable real time communication systems

The system stability controller located in the System Protection Centre (SPC) prevents instability. In the event of imbalance of generation and load it determines the level of either which must be shed to restore equilibrium dependent on the actual network topology. It does this in two ways:

1. The initial level of power supply or load to be shed in an islanding sector is determined by the power flow to that sector via the interconnecting transmission lines prior to separation.
2. A second stage of shedding will follow based on whether the frequency falls/rises below/above a pre-set values.

Similarly, in the remaining main system load shedding will be initiated based on the power flow over the interconnection transmission lines prior to system separation.

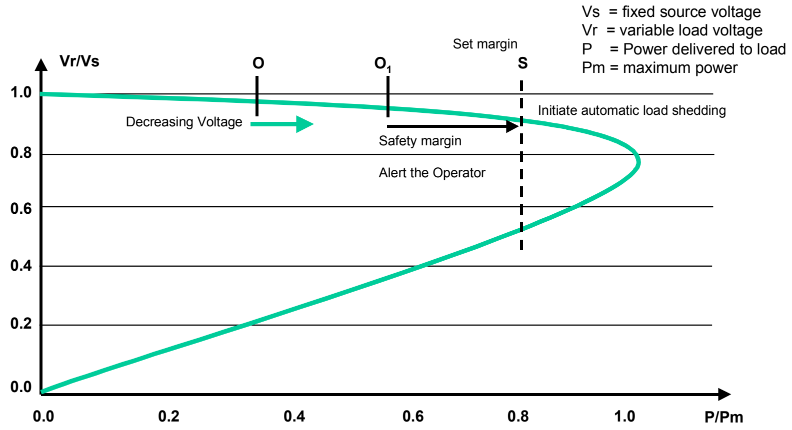
While all phasor measurement evaluations and calculations for load shedding initiation are centrally conducted, substation topology assessment (switchgear status etc.) is performed decentralised in the substation and communicated to the SPC. Conversely, shedding signals generated centrally will initiate transfer trip for load/generation only if the local under-frequency or frequency rate of change relay has also responded.

3.2 Protection against Voltage Instability

3.2.1 Prediction of Voltage Instability (VIP)

The power transfer characteristic of a transmission line is defined by the Power/Voltage characteristic as indicated below. The maximum power Pm, which can be transferred is reached if the load impedance is equally low as the line impedance. With increasing load the voltage declines gradually until P/Pm = 1. After this working point has been surpassed the voltage collapses rapidly until no power can be transferred across this transmission line anymore.

For the prediction of incipient voltage instability, the line voltage is continuously monitored and its status is transmitted on-line. If the operating point “O” is moving and reaches the pre-set point “O_1”, the dispatcher is alerted and advised to take action. He is informed that the risk for voltage instability on the transmission line has increased due to heavy load and he is notified about the safety margin left until instability will occur. Once the operating point passes the pre-set margin at point “S”, automated corrective actions have to be taken to counteract voltage instabilities.



System Power Voltage Characteristic

3.2.2 Measures against Voltage Instability

Examinations of the many voltage collapse incidents world-wide generally show that the disturbance progresses in two phases. The first slow phase consists of a gradual voltage decline over a period of many minutes. If certain actions are initiated at that time the final situation will be much less severe. As with frequency instability occurring, two approaches are suggested to counteract voltage instability:

1. The application of emergency early warning systems which monitor voltage profiles throughout the power system and depending of network topology ascertain the level of risk involved. Potentially unstable situations are conveyed to operators.
2. The application of system protection schemes. Various possibilities can be implemented with the numerical technology available:

3.2.2.1 Maximise Reactive Power Resources

The following measures can be provided to counteract a collapsing voltage condition:

- Provide static VAR Compensation (SVC) in areas deemed to be at risk
- Maximise the reactive power output from synchronous machines, if necessary temporarily overloading stator and rotor field circuits
- Provide adaptive protection devices to prevent tripping on overload or overcurrent
- If advantageous reduce generator active power output in order to maximise reactive power levels

The possibilities indicated to change the operation mode of the generators to prevent voltage instabilities can only be applied in connection with numerical generator protection relays which provide the features for automatic parameter adaptation and the acquisition of condition related data from remote.

3.2.2.2 Control of Of Load Tap Changers

On load tap changers when equipped with automatic voltage regulators (AVR) operate progressively tap up as the primary side voltage decreases thus hastening voltage collapse. To prevent this two approaches are possible, but must be applied to **all** transformers with OLTCs down to the distribution level

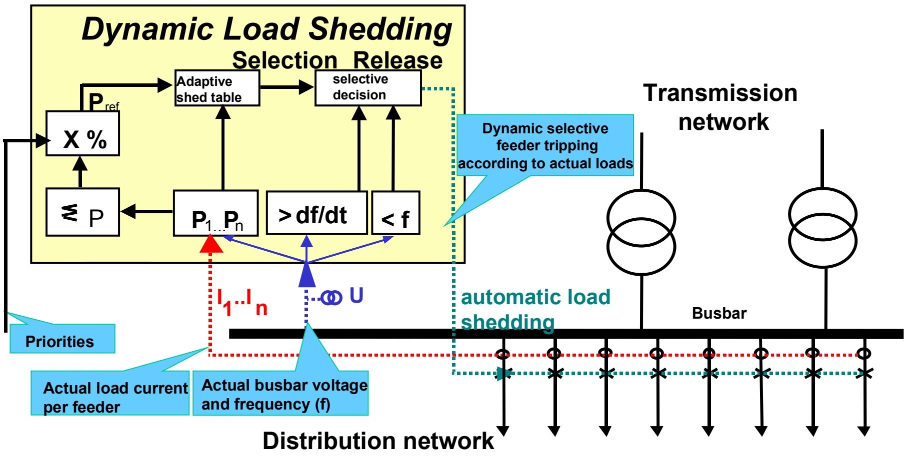
- Block the OLCT once a risk situation has been identified; unblocking ensures once the voltage recovers to an acceptable, stable level. A centrally co-ordinated scheme is possible if adequate communication links are available and if numerical transformer protection relays are installed which can receive a prioritised blocking signal from the SPC.

- Adapt the AVR set point, this is more advantageous than simple blocking as it reduces the load.

3.2.2.3 Load Shedding

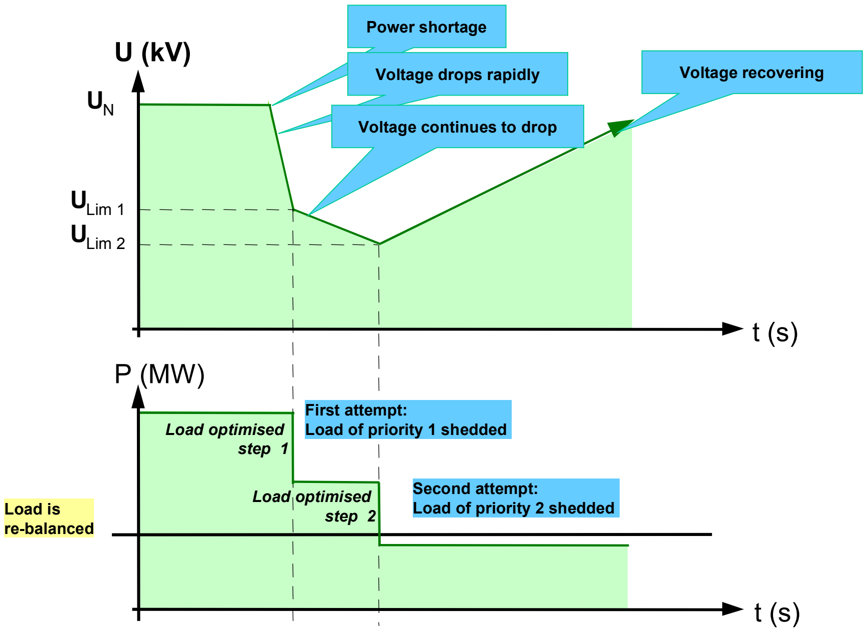
The most common form of protection against voltage instability is undervoltage actuated load shedding. It is the last defence measure for avoiding voltage collapse. Highly reactive loads are shed once the voltage drops to a predetermined level for a pre-set time. It has to act automatically in order to avoid operator delays in case of rapid voltage collapses. Such a scheme requires careful design as it must distinguish between a genuine voltage collapse and a voltage depression for other reasons, e.g. transient fault, aftermath of clearances total loss of voltage supply.

In comparison with conventional load shedding schemes numerical technology offers new solutions as outlined in the ABB solution below:



The numerical overcurrent protection relays in the feeder of the distribution network allow actual measurement of all load currents and the busbar voltage. Together with the priorities, which are predetermined by the user, the system allows to compute a optimised load shedding scheme according to the actual situation rather to work against firmly programmed patterns.

The degree to which load must be shed is determined by success or failure of the actions to reduce the severity of the disturbance during its initial phase as indicated below.



3.3 *Measures against Cascade Tripping*

Analysis of many disturbance has shown that if more time were available to operators, their intervention to reduce load, get reserve plant on stream or take corrective measures would significantly contribute to avoiding complete voltage collapses that eventually result. Good communications to substations and regional control centre, numerical technology for measurement control and protection as well as good tools are essential to success.

The overload thermal capability of any circuit relates both to overload magnitude and duration. It should be possible for effective remedial action to be executed within minutes of a disturbance occurring and therefor overloading for this period should, in most cases, not pose a problem for the equipment. The availability of numerical protection relays with adaptive techniques make it possible to temporarily increase line overloads provided the line equipment can cope with it. The adaptive settings have to include both current magnitude and duration. Similarly allowing generator plant to temporarily increase reactive power output above rated value can provide essential voltage support at a critical time.

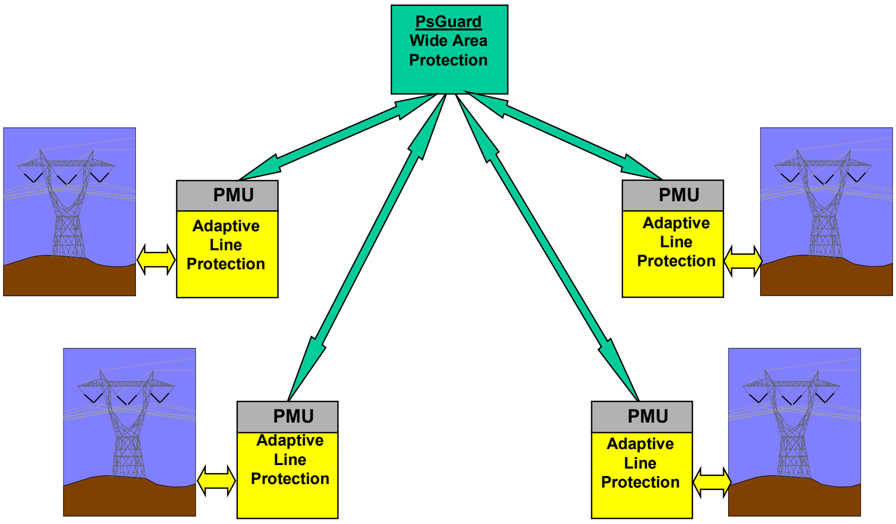
Such schemes are only effective if accompanied by a system of either quickly getting active and/or reactive power reserves on stream or, failing this, ensuring that the load shedding schemes in place reduce demand to a level which the system can meet.

In other words an overall co-ordinated approach is required and a VIP scheme is a capable to for providing the information needed to response in time.

4 “PsGuard” – the ABB Solution for Wide Area Protection

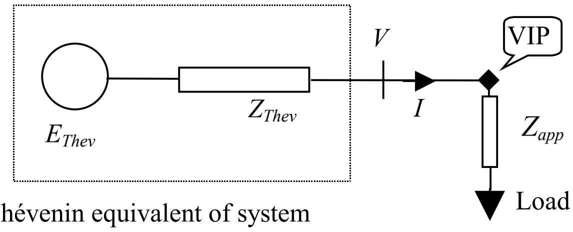
4.1 Voltage Instability Prediction (VIP)

A new technology has been developed by ABB for the detection of incipient voltage instability. PsGuard comprise a number of Phasor Measurement Units (PMU) and a central evaluation unit. The PMUs are located at strategic points throughout the power system. They contain an algorithm that calculates the stability of the various power line transfer conditions based on local measurements of voltage and current phasors.



The voltage instability prediction (VIP) is based on the Thévenin law and the equivalent circuit shown below:

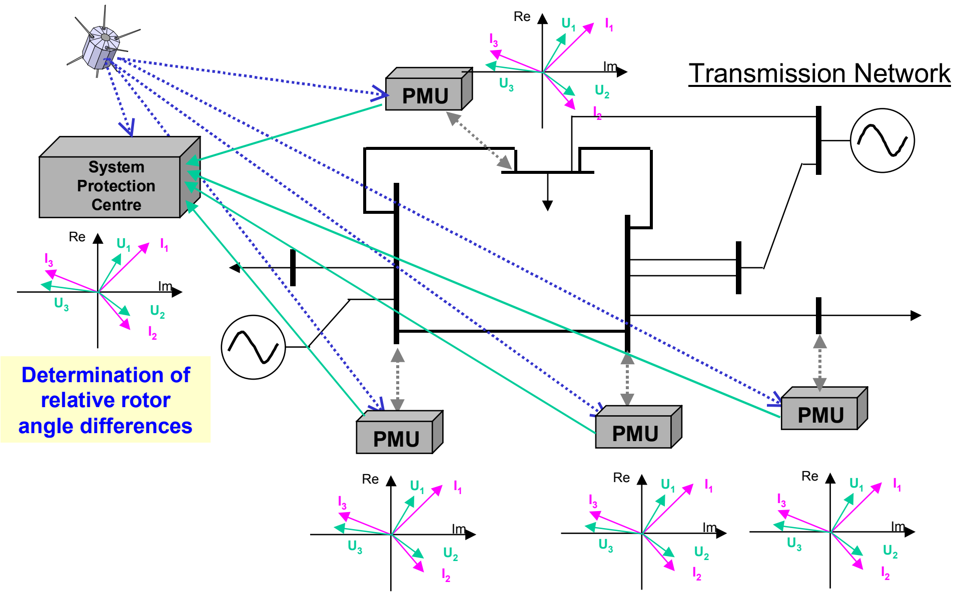
In normal cases the load impedance Zapp >> line impedance *Zthev* . From circuit theory, maximal power transfer occurs when |*ZThev*| = |Zapp|. If |Zapp| becomes smaller than |*ZThev*|, the power transfer capability starts to decrease rapidly and the voltage becomes unstable. The magnitude difference between |Zapp| and |*ZThev*| is an indication for the risk of voltage instability to occur. This difference is expressed in terms of a power transmission *safety margin* to indicate how close the transfer condition is to voltage collapse and to determine the amount of additional power that can still be transferred across the specific transmission line concerned.



Local bus and system Thévenin equivalent.

4.2 *System Wide Performance Monitoring*

In the decentralised PMUs snapshots of the 3 phase voltage and current phasors are taken at all locations and synchronised by the satellite Global Positioning System (GPS). The central evaluation unit reads these voltage and current phasor measurements to monitor the system integrity by determination of the relative rotor angle differences as shown in the graph below.

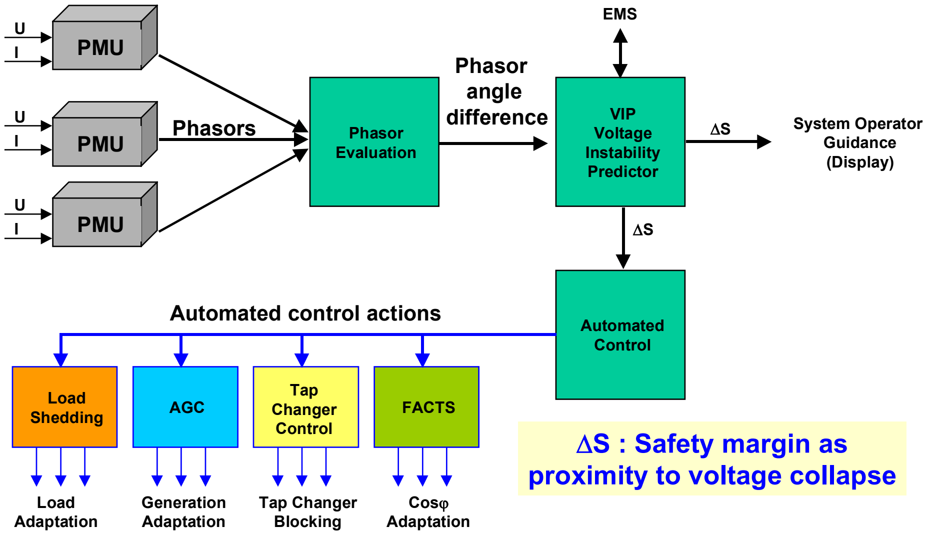


4.3 *Response to Incipient Voltage Instability*

In case of incipient voltage instability detection, two types of instructions are issued:

1. Alerting the system operator by indication of the remaining safety margin ΔS and by providing on-line guidance to counteract this situation. In addition, corresponding information is produced as input for the energy management system (EMS).
2. Automatic control actions are initiated if the safety margin ΔS reaches a pre-set critical level to avoid voltage instabilities to occur, e.g.
    - To compensate the lack of reactive power by FACTS (Flexible AC Transmission Systems)
    - To block the OLTCs (On-lin Tap Changer Controller) in order to avoid over compensation.
    - To maximise the reactive power output from synchronous machines, to compensate the lack of reactive power.
    - To shed load as last defence measure

The block diagram below shows the interactions between the various applications.



5 System Restoration

The two objectives to be achieved during any major disturbance are

- To preserve the integrity of the transmission grid by shedding load and/or generation as required
- To restore supply tp all consumers in the shortest possible time

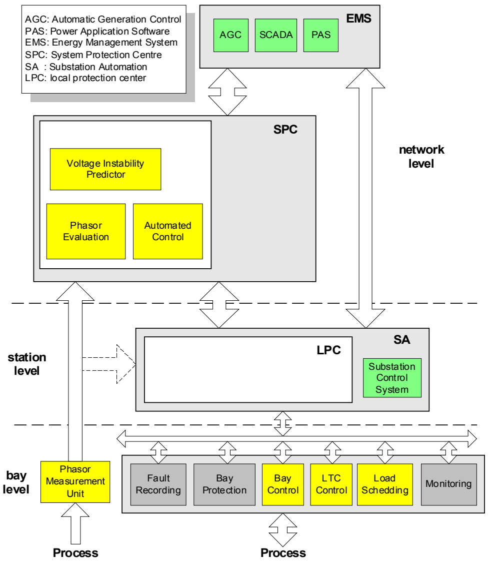
With an effective islanding system in place considerable advantage can be obtained from well-designed auto-restoration schemes. Integrated numerical control and protection devices in a substation automation system enable to design intelligent automated restoration schemes.

6 Decision Support Systems

During disturbed condition data from disturbance recorder, information on network configuration, protection relay signal data and operational procedures all need to be considered when arriving at the appropriate decision for corrective action. This can be problematic due to data volumes and the limitations to the amount of information and real-time performance, which can be managed from SCADA and handled by an operator. The advantages of an automated system located in the substations, which accelerates the automation process, are obvious. The corresponding system structure below shows the allocations of functions and the communication links.

PsGuard System Architecture:

- **PMUs, Phasor Measurement Units**
  - **Measurement of U and I Phasors**
  - **Time stamping and transfer of phasors**
  - **Located at certain places in the network**
- **Phasor Evaluation**
  - **Collection of phasors from PMUs**
  - **Processing, storage and forwarding to VIP**
- **VIP, Voltage Instability Predictor**
  - **Calculation of ∆S**
    Power margin as “closeness to collapse”
- **Automated Control**
  - **Control actions based on ∆S**



The rapid development in numerical technology and expert systems has made the realisation of such systems possible. A decision support system (DSS) uses data downloaded from system transient monitors, disturbance recorders, fault locators, and protection relays. A DDS, which is integrated in a SA system, has the potential to improve operational performance by:

- Improving supply to customer through analysis of protection and other secondary system performance: weakness can be identified and corrective action undertaken
- Increasing the speed of operator response and reducing operating costs through the automation of fault analysis and decision making

7 Conclusions

With the advances in the development of numerical technology and digital braodband communication more sophisticated systems can be applied in the field of power system control and protection. Today’s protection devices are ceasing to be confined to the protection of specific plant objects. The application of adaptive techniques allows protection schemes such as line distance relays, auto-reclosing schemes or overcurrent based devices to modify their response to disturbed events based on system conditions. This enables them to respond in a manner best suited to system preservation. Furthermore, due to the availability of broadband, fast communications permit the deployment of protection schemes dedicated to the preservation of system integrity through co-ordinated actions. The implementation of preventive operational strategies in conjunction with comprehensive use of numerical technology will undoubtedly reduce the risk of catastrophic large area disturbances.