AN EXPERT SYSTEM FOR WIDE AREA BACK-UP PROTECTION:- LOCAL DRIVEN MECHANISM WITH REMOTE INFORMATION SHARING

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Abstract – A decentralized wide area back-up protection scheme, based on substation based local driven mechanisms with remote information sharing, is described and evaluated in the paper. The scheme prevents widespread blackouts by selectively localizing its response to a fault that failed to be cleared by the main protection. The information sharing mechanism defines how the wide-area information should be acquired and shared, which circuit breakers should be tripped and where the intertrip signals should be sent. Examples demonstrate how information is shared between the individual devices that implement the Back-up Protection Expert System (BPES) and how each device isolates a fault on a double circuit network.

Keywords: Protection Relay, Back-up Protection, Wide Area Protection, LAN/WAN Communications, Transmission Network, Expert Systems.

1 INTRODUCTION

Recent blackouts have raised concern about the use of time delayed distance and overcurrent relays for back-up protection. In North America, maloperation of protection relays or an inappropriate operating response was associated with 75% of the major transmission network disturbances. Relays and in particular time delayed back-up protection often initiated or propagated disturbances through the network. Conventional relays process the voltage and/or current signals measured locally and in the case of back-up protection use this limited view of the network to try to decide if a remote fault has occurred and where it is located. Effectively, the relay takes an action that is a part of the overall protection response, but it does not consider the impact of its action on the complete network. Operation of back-up relay may trip a circuit breaker that is remote from the fault, i.e. a non-selective response, or may maloperate due to load encroachment or a transient swing. The shock to the network may occasionally initiate or propagate a sequence of cascading trips that leads to a widespread blackout. Power utilities need to review their traditional approach to back-up protection and consider the impact of non-selective tripping with inadequate levels of security [1,2].

The real time information processing capabilities of today's computer systems plus advances in communication networks, and in particular the agreement on inter and intra substation communication standards, has allowed protection relays to broaden their view of the network. No longer is it necessary to only process local information, relays can now enhance their capabilities by receiving protection and topological information from remote sites [3].

This paper describes how a local driven mechanism, in conjunction with remote information sharing, can be used in an expert system for wide area back-up protection. The system is a decentralized, substation-based back-up protection scheme that reduces the risk of widespread blackouts by localising its response to faults that failed to be cleared by main protection. The system acquires wide-area information via substation local area networks (LANs) and regional wide area networks (WANs). It then uses it to monitor the operational response of conventional relays and if appropriate trips the circuit breakers necessary to selectively isolate the fault [4]. This new approach to back-up protection prevents cascading outages by restricting the trip decision to those circuit breakers that must operate to clear the fault, and by blocking the time delayed trip signals sent to other breakers by conventional back-up relays [5]. The system must operate faster than conventional back-up relays and must have a panoramic view of the protected network that allows it to locate a fault precisely and to block any unnecessary trip decisions. The paper discusses how wide area information is acquired and shared between the individual devices that implement the overall back-up protection system. A local driven mechanism is developed which defines how a BPES device is activated, a circuit breaker is tripped and how far an intertrip signal should be sent to ensure reliable fault clearance [6,7]. Examples are given to demonstrate how information is shared once a fault occurs on a simple double circuit network.

2 OVERVIEW OF THE BACK-UP PROTECTION EXPERT SYSTEM

A BPES device is a substation node in a decentralized back-up protection expert system. It receives information from the breaker bays in its own substation via the LAN and from remote BPES devices in adjacent substations via the WAN. Each device normally operates in a standby mode but transfers to emergency protection mode when a conventional relay detects a fault.

During standby, each BPES device monitors the operational response of all the feeder protection relays in the local substation. This involves analysing information received directly from IEDs, digital relays or the interfaces that acquire information from legacy type relays, and older electronic and electromechanical relays. During standby only the Monitoring System is active. The Expert System in the BPES device stays inactive until a fault is detected. Operational information from protection relays and circuit breakers is acquired at every sampling interval, which in the present implementation is 10ms. When a sample arrives at a BPES device, the Monitoring System extracts the sample and compares it with the previous sample. Any difference indicates an event that might be related to a switching action or a short circuit fault.

If an event is detected the system calls the network configuration tracking component. This updates the information held in the BPES and initiates a timer that when expired triggers the Expert System. A time delay is necessary to ensure priority is given to the main protection and also to allow the BPES device time to collect sufficient information from all the adjacent substations. The BPES Monitoring System continuously monitors the operational response of all conventional feeder protection relays and the open/closed status of circuit breakers at the local substation. This information is updated in the Expert System when the pre-set time delay has expired and the Expert System invoked.

To reach a decision, the Expert System generates an initial fault affected region (FAR), which includes all the lines and busbar sections likely to be affected by the ault. It then evaluates the action factors associated with each component in the FAR and calls the Level 1 decision process. This tries to locate a faulted component using information only available from that component. If a final decision cannot be reached, it calls the Level 2 decision process. This starts from the initial FAR and makes every effort to reduce the size of the region. Once this has been completed, the Level 2 decision process claims a fault somewhere within the final FAR and invokes a certainty evaluation process to determine where the fault is most likely to be located. If the final FAR contains a single component, or if a Level 1 decision had been achieved, the fault has been localized and the trip and intertrip instructions are classified as Level 1. The Expert System issues these instructions to the circuit breakers at the extremities of the component, which is then isolated from the network. The Expert System also issues blocking signals to the relays that have been activated but tripping their breakers is regarded as unnecessary. An intertrip signal is first delivered to the remote BPES device where the signal is passed to the control IED which opens its associated circuit breaker. Blocking instructions will not be issued, if a Level 2 decision with multiple items, is evaluated for the final FAR [5].

3 INFORMATION SHARING

To precisely locate a fault and to have the confidence to block any time delayed trip signals issued by conventional relays, the BPES must have a global view of the protected network. To achieve this, a BPES device needs to exchange information with other BPES devices, using the mechanisms described in section 3.1 and 3.2.

3.1 IP Multicasting Protocol

Assume a dedicated Wide Area communication Network (WAN) has been established and is integrated into the UCA2.0 or IEC61850 communication highway. The dedicated transmission WAN joins together all the substation, generation and control centre LANs. It makes information available at one substation accessible to others. A typical transmission network WAN is based on a dual counter-rotating ring with link loss self-healing functions, see Fig.1. This ensures message delivery between substations is guaranteed and information exchanges are relatively easy, simple and secure.

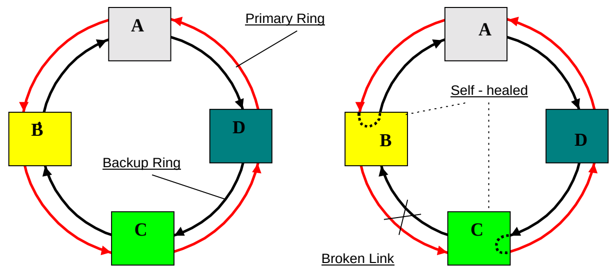

Fig.1 Self-healing dual ring architecture

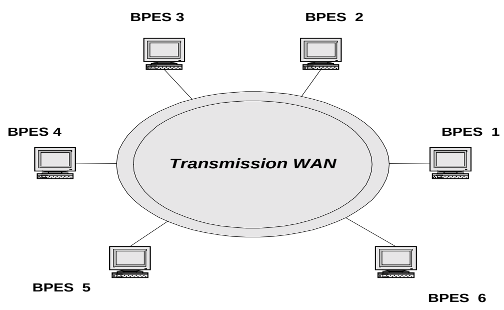

Fig.2 Transmission WAN

If one assumes the Generic Object Models for Substation and Feeder Equipment (***GOMSFE***) becomes an international standard, and if protection tripping over the LAN can be achieved within 4ms by using a ***GOOSE*** technique, information sharing between the BPES devices is simple and easy, see Fig.2. All BPES devices that need to receive information from a single BPES device must be capable of extracting contact information from this device. By multicasting the tripping signals to a list of BPES devices using GOOSE technology, the BPES can directly trip circuit breakers using the LAN as a communication medium.

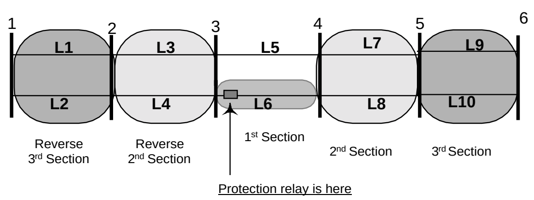

Fig.3 Section definition

If one considers the reach or coverage of a reverse looking zone 4 distance element or a zone 2 forward looking element, each BPES device must talk to its second neighbour to collect sufficient information to isolate a fault. Using the example shown in Fig.3:- a zone 2 element on L6 at substation 3 can detect a fault on L6, L7, L8 and L5 and the zone 4 element at the same location can detect a fault on L1, L2, L3, L4 and L5. Consequently, the BPES device at substation 3 must receive information from BPES devices at its 1st neighbours 2 and 4 and its 2nd neighbours 1 and 5. Similarly, because a zone-3 distance element can detect a fault beyond its second neighbour substation, the BPES must collect information from its 3rd neighbours. For the example shown in Fig.3: the zone 3 element on L6 at substation 3 can detect a fault on L7, L8, L9, L10, L5 and also, if the element is offset L3 and L4. Consequently in addition to its 1st and 2nd neighbours the BPES also needs information from its 3rd neighbour substation 6. To ensure a BPES device correctly monitors the operational response of conventional relays it must have a global view of the network and receive information from line protection relays located at its 1st, 2nd and 3rd neighbour substations [8,9].

3.2 Peer to peer connections

In the existing BPES, information sharing is via peer-to-peer connections operating over the WAN communication network as shown in Fig.4. If a connection fails; for example, between BPES 5 and 6, information from BPES 5 can still be delivered to BPES 6, but it now involves a transfer through BPES 4,3,2 and 1.

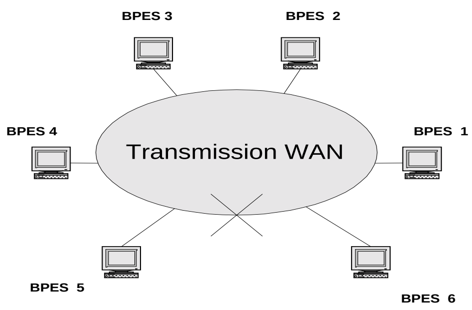

Fig.4 Communication failure on WAN

For networks that are effectively radial in their construction, a second communication path is required for the end substations. This helps ensure high reliability by effectively providing an alternative communication route. The example shown in Fig.5 indicates that if a connection between the two end substations (1 and 7) can be established, a communication ring network exists and high reliability communications is achieved.

Information sharing between BPES devices is based on a SNAP SIB facility. SNAP is a real time expert system shell, and its SIB facility provides real time information sharing between remote devices. Any changes in a local BPES device can be reflected in the remote BPES

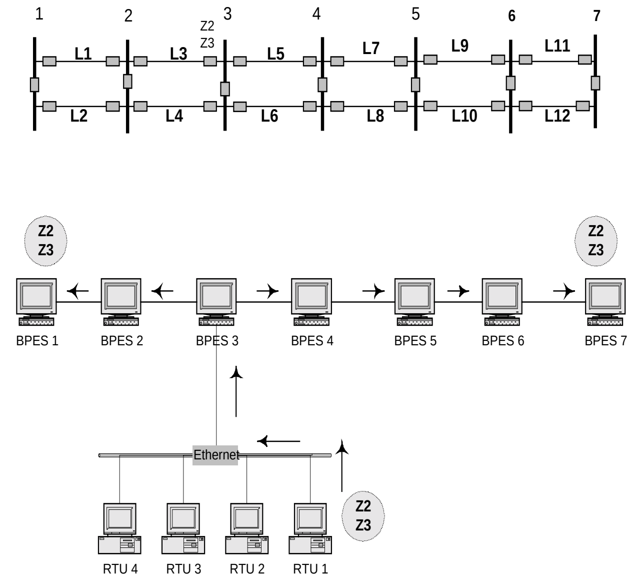

Fig. 5 Information sharing

devices where sharing information has been defined. These changes are updated asynchronously in the BPES.

For example, if we consider the DISTANCE RELAY class and the following attributes are shared; any changes in these attributes will be automatically updated in the remote BPES devices that are peer-to-peer connected. For example:

Zone 1	Signal Sent
Zone 2	Flag A
Zone 3	Flag B
Zone 4	Flag C

If a shared attribute of a member in the DISTANCE RELAY class is changed, the attribute in the corresponding member in a remote BPES device will be updated automatically. For example, the acquired zone 2 and zone 3 signals at BPES 3 will update the corresponding attributes in BPES 2 and BPES 4, which lead to the updating of BPES 1 and BPES 5. Eventually, the corresponding attributes in BPES 7 will be updated. The operated zone 2 and zone 3 elements in a distance relay at BPES 3 initialises a chain of events that lead to the updating of the attributes in the overall BPES system. Shared attributes in the BPES are updated asynchronously.

4 LOCAL DRIVEN MECHANISM

To acquire the information necessary for the optimal isolation of a fault, a Local Driven Mechanism was developed and introduced into the BPES system. The Local Driven Mechanism defines how an expert system is activated, how a circuit breaker is tripped, and the number of lines over which an intertrip signal should be sent if reliable fault clearance and adequate redundancy are to be ensured [10].

4.1 Activation of an Expert System

Rule 1: An Expert System in a BPES device will be called to investigate a fault, if one or more protection relays at the substation have detected the fault and are active. The Expert System can only be driven to make a decision by the active protection relays at the local substation.

Rule 1 ensures the Expert System in a BPES device usually operates in a standby state. It is activated when a fault is detected by a protection relay in the substation where the BPES device is located. The Expert System is triggered when a timer initiated by the active relay has expired. The timer which generates a **Communication Delay** of 200ms is necessary to ensure priority is given to the main or primary protection. It also provides sufficient time for each BPES device to collect information from their 1st, 2nd and 3rd neighbouring substations. This ensures each BPES device has a global view of the network. Which allows it to precisely locate the fault and to selectively trip the circuit breakers that must open to clear the fault. Fig.6 demonstrates how an Expert System in a BPES device triggers when a fault occurs on L5. The initial response is listed in Table 1.

Table 1: Initial response of BPES Expert Systems

BPES 1	Expert System remains stable.
BPES 2	Expert System activated: fault detected in zone 3 by distance relays on L3 and L4.
BPES 3	Expert System activated: fault detected in zone 2 & 3 by distance relays on L5 & L6.
BPES 4	Expert System activated: fault detected as reverse zone 4 on L7, L8 and L6.
BPES 5	Expert System activated: fault detected in zone 2 & 3 by distance relays on L7 & L8.
BPES 6	Expert System activated: fault detected in zone 3 by distance relays on L9 and L10.
BPES 7	Expert System remains stable.

4.2 Tripping of a Circuit Breaker

Rule 2: A circuit breaker can only be tripped by an instruction issued by the BPES device at the local substation.

Rule 2 states that a BPES device is authorised to issue a trip instruction to a circuit breaker in its own local substation. A circuit breaker cannot be directly tripped by a BPES device in a remote substation.

If a circuit breaker is interfaced to the substation LAN by a breaker control IED it can be tripped directly over the LAN by the BPES device. Alternatively, a breaker can be tripped via a normally open contact in the BPES device connected electrically to the trip coil.

If an Expert System needs to trip a circuit breaker at a remote substation, an intertrip instruction is issued. The intertrip instruction signal is delivered via the WAN to the BPES device at the selected substation. On receipt of this signal, the remote BPES device immediately trips the chosen breaker.

4.3 Transfer of Intertrip Signals

Rule 3: A BPES device can only intertrip circuit breakers in adjacent substations. The intertrip instruction is sent to the BPES device in this substation, which transfers it to the chosen breaker.

Rule 3 states that a BPES device is only authorized to issue an intertrip instruction to a circuit breaker located at one of its immediately adjacent substations and this instruction must be delivered to the corresponding BPES device. On receipt of this instruction, the remote BPES device immediately sends a trip signal to the chosen breaker.

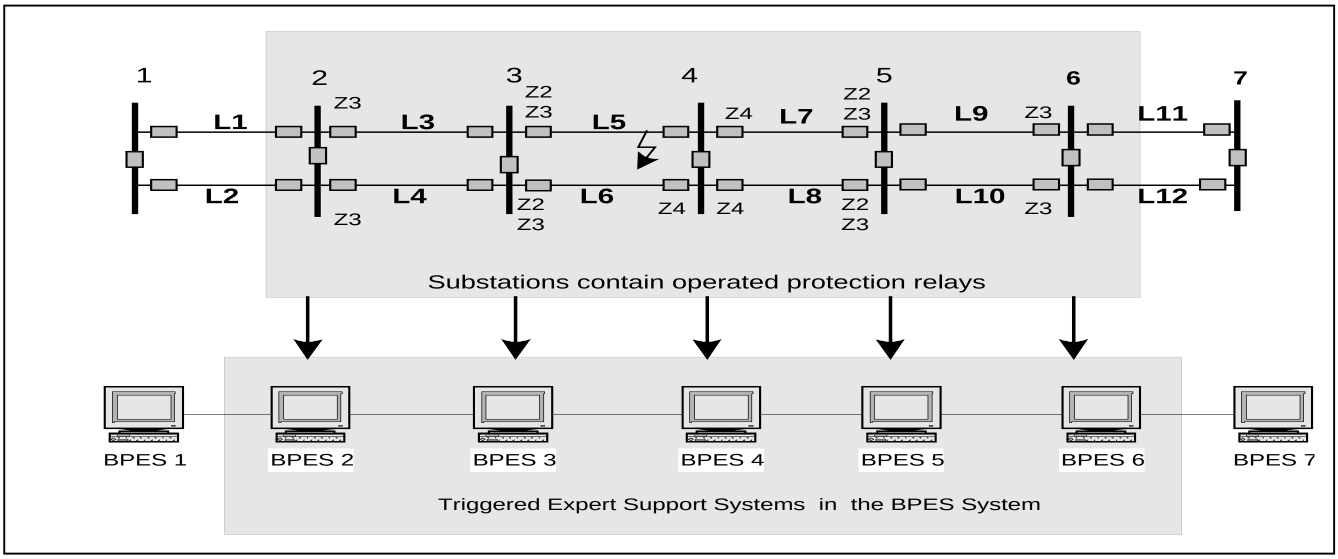

Fig.6 Activation of BPES

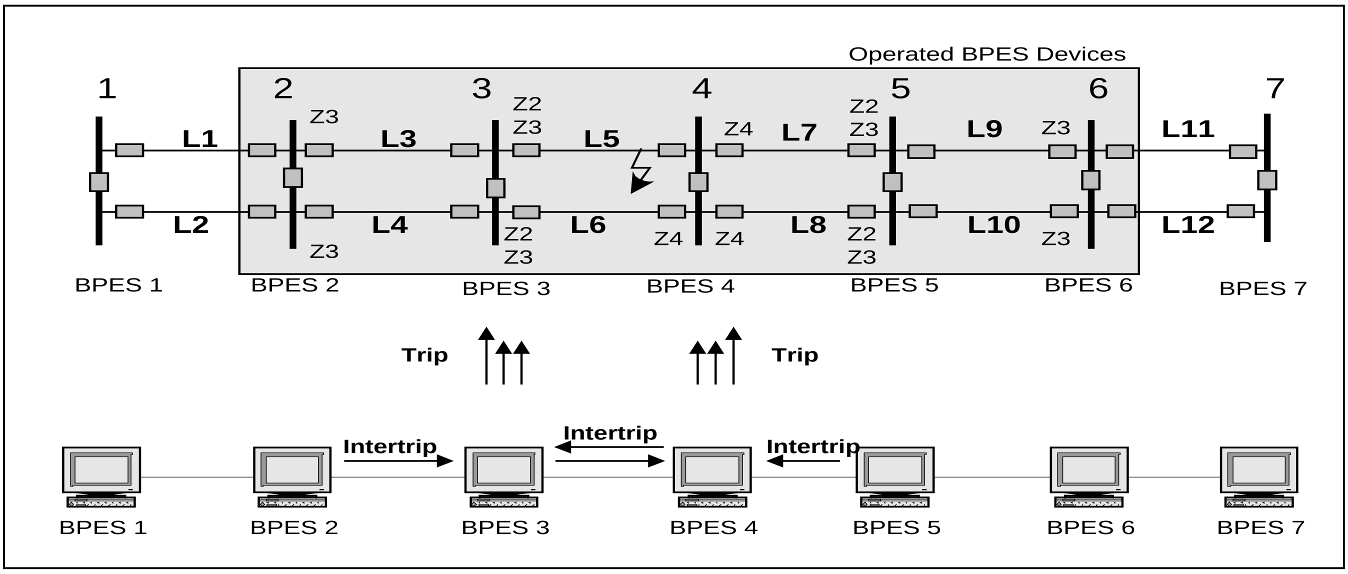

Fig.7 Intertripping of circuit breakers in adjacent substations

Fig.7 shows that a fault on L5 was detected by relays at substations 2, 3, 4, 5 and 6. The BPES devices at all five substations conclude that the fault is on L5. BPES 2 sends an intertrip to BPES 3, which trips the breaker on L5 at substation 3. Similarly, BPES 5 sends an intertrip to BPES 4, which trips the breaker on L5 at substation 4. BPES 6 does not issue an intertrip command because the fault is outside the domain of its first neighbour. At BPES 3, a trip signal is sent via the LAN to the breaker on L5 in its local substation. BPES 3 also sends an intertrip signal to BPES 4, which then sends a trip signal to the breaker on L5 in its own substation. Similarly BPES 4 sends a trip signal to the local L5 breaker and via BPES 3 an intertrip to the L5 breaker at substation 3.

4.4 Blocking of Additional Trips

Rule 4:
A BPES device will block any trip decisions in its own local substation that are not required for fault isolation. A trip block command is only activated when a definite fault location decision has been achieved by the BPES.

Rule 4 states that if the fault is definitely not on a line or busbar protected by the BPES device, then a trip decision initiated by a conventional back-up relays in the local substation is incorrect and must be blocked. Such trips could be caused by overloading, incorrect settings, hidden failure, or by inherent limitations in conventional back-up protection. To block a trip decision the BPES device either sends a blocking signal to its associated circuit breaker controller or the operated relay if it is capable of responding to such a signal. This rule indicates that the BPES should block the tripping of any lines parallel to the faulted line if it is initiated by back-up protection. This may prevent load encroachment initiated by the tripping of the faulted line and the transfer of load to the parallel line.

The blocking actions issued by the BPES system for a fault in Fig. 8 are stated in table 2. The strong source (busbar 1) refers to a large generating station with a high fault level. This provides bulk power for transfer via the double circuit network to the main load centre at busbar 7. Limited generating capability is available at busbar 7 and consequently it can only behave as a weak source for a fault on the network.

Table 2: Blocking decisions in the substations

BPES 1	BPES device stays stable
BPES 2	BPES has detected the fault but all circuit breakers being tripped are remote. The BPES sends blocking signals to the distance relays on L3 and L4 at the substation and blocks the trips from these relays.
BPES 3:	BPES has detected the fault and reached a Level 1 decision. This requires the tripping of the circuit breakers at either end of the faulted line L5. The BPES issues trip signal to open the circuit breaker on L5 at the substation and an intertrip signal to the far end BPES device. It also issues a blocking signal to the distance relay on L6 at the substation.
BPES 4	BPES device issues trip signal to open the circuit breaker on L5 at the substation and an intertrip signal to the far end BPES device at substation 3. No blocking signal is issued as no forward looking elements have operated at the substation.
BPES 5	BPES has detected the fault but all circuit breakers to be tripped are remote. The BPES sends blocking signals to the distance relays on L7 and L8 at the substation and blocks any trips activated by these relays.
BPES 6	The BPES device stays stable
BPES 7	The BPES device stays stable

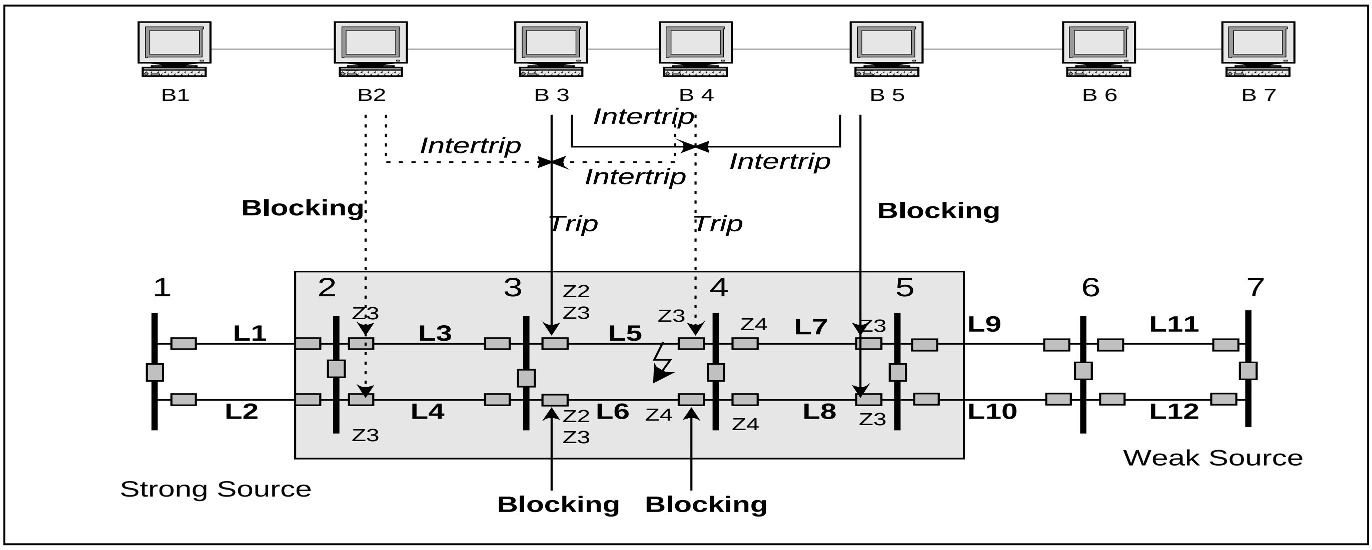

Fig.8 Blocking of additional trips

5 CONCLUSIONS

The paper described how information is acquired and shared in a wide area back-up protection expert system that utilises a local driven mechanism and information sharing between distributed devices. Examples are given to demonstrate how information is transferred between BPES devices and how each device is activated to isolate a fault on a double circuit line system.

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