This is the accepted version of this conference paper:


© Copyright 2001 ICCAS/IEEE
Abstract

A high peak power demand at substations will result under Moving Block Signalling (MBS) when a dense queue of trains begins to start from a complete stop at the same time in an electrified railway system. This may cause the power supply interruption and in turn affect the train service substantially. In a recent study, measures of Starting Time Delay (STD) and Acceleration Rate Limit (ARL) are the possible approaches to reduce the peak power demand on the supply system under MBS. Nevertheless, there is no well-defined relationship between the two measures and peak power demand reduction (PDR). In order to attain a lower peak demand at substations on different traffic conditions and system requirements, an expert system is one of the possible approaches to procure the appropriate use of peak demand reduction measures. The main objective of this paper is to study the effect of the train re-starting strategies on the power demand at substations and the time delay suffered by the trains with the aid of computer simulation. An expert system is a useful tool to select various adoptions of STD and ARL under different operational conditions and system requirements.

1. Introduction

Under pure MBS [1], two successive trains are separated by a distance equivalent to the necessary braking distance for the train behind to brake to a halt from its current speed, together with a safety margin, instead of protected by physical signalling blocks with fixed block signalling [2][3] system. As the separation between the two trains varies with the speed of the train behind, a hypothetical block of a braking distance is considered to be moving along with the train in front as illustrated in Fig 1. The movement of the train behind is regulated by the difference between its current speed and the target profile.

When a train stops for an unexpectedly long period of time under pure MBS, the trains behind are forced to stop, forming a dense queue. When the trains begin to move again, they can actually accelerate simultaneously and incur a very high instantaneous demand on the power supply system. The circuit breakers will be tripped at the power feeding substations nearby and the service will be interrupted unless there is provision for a much higher power ratings within the power supply system.

![Moving Block signaling separation](image)

Fig. 1 Moving Block signaling separation

Measures of Starting Time Delay (STD) and Accelerating Rate Limit (ARL) to reduce the peak power demand under MBS have been introduced in a recent study [4]. Promising results were obtained as certain reduction has been achieved. Nevertheless, there is no well-defined relationship between the above two (STD and ARL) or any other possible measures and the amount of peak power reduction, analytical or otherwise.

To determine which PDR measure should be enforced and to what extent, a number of application-dependent factors, such as track layout, distribution and number of trains, balance between energy consumption at substations and time delay already suffered by trains; and the actual implementation of MBS, have to be considered. The use of any peak-demand reduction measures should be made adaptive to the traffic conditions and system requirements. As a result, actions from human operators are usually...
needed to regulate the re-starting process of a queue of trains under MBS. Expert knowledge, common sense and facts on railway operation and safety constraints are required to reach a reasonable solution. An expert system is therefore a useful tool to formalise the expert knowledge and derive the appropriate use of peak-demand reduction measures.

This paper will first discuss the general PDR techniques and hence their impacts and limitation on the peak-power demand reduction. With the aid of computer simulation, the knowledge base of the expert system is established with various extents of adoptions of STD and ARL, taking into account of a wide range of possible operational conditions and system requirements. The expert system has the usual components of knowledge base, user-interface and inference engine and their structures will be presented in the paper. A few examples will also be given to illustrate the performance and applicability of the expert system.

2. Peak demand reduction technique

In general, one of the possible measures to reduce the peak power demand at substations is to avoid moving trains at the same time by giving some time delay to the following trains. Another possible approach is to adjust an acceleration rate to the following trains as possible. These two PDR techniques are defined as follows.

STD: the following trains are given some time delay with respect to the train in front according to the headway time between two successive trains under MBS.

ARL: the acceleration rate of the following trains is adjusted with respect to the train in front according to the headway distance between two successive trains under MBS.

3. Expert system

An expert system is a computer program that provides assistance in solving difficult problems normally handled by human experts [5]. It stores knowledge of how a particular type of problem is solved and uses the knowledge to infer a solution. Conventional programs are designed to solve problems for which all the factors used in the decision-making process can be completely analysed. Typically, this analysis can be defined in a particular algorithm. Nevertheless, expert systems are aimed at problems that cannot always be solved using a purely algorithmic approach. These problems are often characterised by irregular structure, incomplete or uncertain information, and considerable complexity.

A common problem-solving approach used by an expert system is to propose a solution and then prove its validity. To determine the cause, or causes, the inference engine accesses the knowledge base and systematically applies its rules to facts about the problem. These facts are obtained from the end user and stored in the expert system’s context file. The inference engine is a software module that executes procedures of applying knowledge to produce new information about a problem. In production rule systems, an inference engine compares rules against known facts in the context file to determine if new facts can be inferred. The conditions in the premises, or IF part, of a production rule are compared against known facts. If these conditions are satisfied, the facts in the conclusion, or THEN part, can be inferred. To solve a specific instance of a problem, a large number of rules may have to be examined. An inference engine uses an inference strategy to guide the order by which rules are examined and inferences made. Inference strategies are an important aspect of expert system and the forward chaining approach is used in this study.

The structure of the expert system is illustrated in Fig 2.
Facts related to the train operation in a railway system are listed as follows.
1. Total number of trains running along the line
2. Total number of trains for restarting control
3. Maximum number of trains in a queue
4. Starting location of each train with respect to the locations of substations
5. Weight of each train (in rated value)
6. Level of quality of service (three levels are defined, high, moderate and low)
7. Level of energy consumption (three levels are defined, high, moderate and low)

4. Simulation results

4.1. Simple PDR techniques

The simulation results in the following section 4.1.1 and 4.1.2 are based on the traffic and system conditions below.
1. Three trains run along the line
2. Two substations are on the line, one of them is located at the restarting point (i.e. substation A) and the other is placed at the last passenger station (i.e. substation B)
3. Separation between substations is 1.705km
4. Headway is 90 seconds

4.1.1. Starting time delay (STD)

The peak power reduction on the two substations under STD is given below.

<table>
<thead>
<tr>
<th>Time delay arrangement (sec)</th>
<th>Peak power reduction at subst. A (%)</th>
<th>Peak power reduction at subst. B (%)</th>
<th>Stop time of last train (mm:ss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0</td>
<td>0</td>
<td>0</td>
<td>11:53</td>
</tr>
<tr>
<td>10-20</td>
<td>7.27</td>
<td>17.51</td>
<td>11:56</td>
</tr>
<tr>
<td>10-30</td>
<td>7.27</td>
<td>4.62</td>
<td>11:57</td>
</tr>
<tr>
<td>20-20</td>
<td>2.98</td>
<td>1.86</td>
<td>11:56</td>
</tr>
<tr>
<td>20-30</td>
<td>10.53</td>
<td>-0.98</td>
<td>11:58</td>
</tr>
<tr>
<td>30-30</td>
<td>12.5</td>
<td>4.58</td>
<td>12:05</td>
</tr>
<tr>
<td>30-40</td>
<td>17.96</td>
<td>6.36</td>
<td>12:15</td>
</tr>
</tbody>
</table>

Remarks:
1. The stop time of last train is the time when the last train stops at the last stop station
2. The first case “0-0” is the case for reference only, where “0-0” is that no time delay is given to the middle and last train respectively.

4.1.2. Acceleration rate limit (ARL)

This section investigates the effect of ARL reduction strategy on the peak power demand on the supply system. Simulation result is given below.

<table>
<thead>
<tr>
<th>Acceleration rate adjustment</th>
<th>Peak power reduction at subst. A (%)</th>
<th>Peak power reduction at subst. B (%)</th>
<th>Stop time of last train (mm:ss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1</td>
<td>0</td>
<td>0</td>
<td>11:53</td>
</tr>
<tr>
<td>0.9-0.81</td>
<td>2.9</td>
<td>-7.4</td>
<td>11:54</td>
</tr>
<tr>
<td>0.9-0.63</td>
<td>8.2</td>
<td>-2.5</td>
<td>11:53</td>
</tr>
<tr>
<td>0.8-0.64</td>
<td>5</td>
<td>-12.5</td>
<td>11:55</td>
</tr>
<tr>
<td>0.8-0.48</td>
<td>7.2</td>
<td>-15.6</td>
<td>11:57</td>
</tr>
<tr>
<td>0.7-0.49</td>
<td>4.1</td>
<td>-22.5</td>
<td>11:59</td>
</tr>
</tbody>
</table>

Simulation results show that both STD and ARL provide a lower peak energy consumption on the power supply system. The reduction is further improved when the time delay and acceleration rate to the following trains are further extended and reduced respectively. Moreover, imbalance demands on the two substations is also improved by using the peak reduction techniques. When ARL is employed, the power demand on substation A is distributed more to substation B such that the peak energy demand difference between the substations is significantly reduced. Furthermore, the stop time of the last train can be maintained in ARL but STD introduces more time delay to the following trains. Nevertheless, the drawback of applying the ARL techniques is that its control space is limited by the train traction equipment characteristics when compared with STD (where time delay can be introduced without limitation).

4.2. Application of expert system on train operation

In this case study, the headway is 90 seconds and pure moving block signalling is implemented.
Other operational conditions

1. Performance concern: Energy
2. Level of energy consumption: High
3. Number of trains in sequence: 3
4. Total number of trains running on the line: 5

With the provided operational traffic conditions, the following suggestions are made by the expert system.

1. Trains (5 in total) should be divided into two groups for starting. Group I consists of trains 1, 2 and 3, whereas the next two trains 4 and 5 is in group II.
2. Time delays 20 and 40 seconds are given to the middle and last train respectively.

<table>
<thead>
<tr>
<th>Case</th>
<th>Time separation between groups (sec)</th>
<th>Peak power demand at the front substation (KW)</th>
<th>Peak power demand at the front substation (KW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A*</td>
<td>0</td>
<td>6947.6</td>
<td>4412.6</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>8727.7</td>
<td>5058.4</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>7392.8</td>
<td>4490.6</td>
</tr>
<tr>
<td>D</td>
<td>20</td>
<td>6511.2</td>
<td>4685</td>
</tr>
<tr>
<td>E</td>
<td>40</td>
<td>6354.9</td>
<td>4264.8</td>
</tr>
<tr>
<td>F</td>
<td>60</td>
<td>5361.6</td>
<td>3979.2</td>
</tr>
</tbody>
</table>

* No PDR technique is applied

Simulation results show that the peak power demand at substations in case F can be significantly reduced only if the time separation between the two train groups is adequate when compared with case A. However, when the time separation between train groups is small, the peak power demand at substations cannot be improved and it even becomes worst. It is because free acceleration to the following train is allowed and the power required by front train(s) for acceleration is still high. On the other hand, imbalance condition on the two substations can also be alleviated by further extending the time separation between train groups. Therefore, the effect of time separation between train groups needs further study.

5. Conclusions

A queue of trains restarting under MBS draws a very high peak demands from the supply, which in turn trips the circuit breaker in the supply system and finally interrupts the train service. Simulation result shows that imbalance demand on the two substations can be mitigated by PDR techniques, and it is more effective when ARL is used. Also, it has been proven that the developed expert system can deliver a reliable solution under various traffic conditions. The problem-solving ability of the expert system is much dependent on the completeness of its knowledge base. In conclusion, the PDR techniques can reduce the peak power demand with expert system. However, time delay or acceleration assignment on the following trains should be specifically defined and it requires further investigation.

References