A CASE FOR LOSSES MINIMISATION IN ACTIVE NETWORK MANAGEMENT SYSTEMS

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ABSTRACT

The increasing demand on the UK's electricity network has seen a drive to develop intelligent active network management (ANM) systems. The current passive arrangement of the distribution network is no longer appropriate as the penetration of distributed generation (DG) is increasing and active networks provide a significant cost deferral mechanism to network reinforcements.
Alongside ANM development, minimisation of losses is being incentivised through the Office of Gas and Electricity Markets (Ofgem) as network inefficiencies not only have economic implications but contribute to carbon emissions. This paper presents an ANM system that incorporates an algorithm for the minimisation of losses which is demonstrated on a 300-bus test network.

INTRODUCTION

The UK Government is committed to increasing the amount of energy produced from renewable sources to 15% by 2020 [1] and reducing greenhouse gas emissions by 80% by 2050 [2]. In order to achieve an increased penetration of renewable energy sources distribution networks, that are typically passive, are required to become active networks. One area that has gathered interest in recent years is the concept of a smart grid to facilitate ANM systems to ensure that networks operate as efficiently as possible.

Along with the drive for smart grids, there is an obligation to reduce real power losses in the distribution networks. It is estimated that real power losses at distribution level are responsible for 1.5% of the UK's greenhouse gas emissions [3]. Europe-wide, it is estimated that between 4 and 10% of electricity generated is lost in the networks [4]. It is therefore desirable that electricity networks are actively managed to ensure optimal operation.

The UK gas and electricity sector regulator Ofgem has introduced a loss reduction incentive in the fifth Distribution Price Control Review (DPCR5: 2010-2015) [3]. This incentive sees Distribution Network Operators (DNOs) penalised if they fail to reach their losses reduction target and rewarded if the target is met.

Over the last three decades losses minimisation techniques have advanced considerably. Merlin and Back [5] developed a technique for minimising losses based on the branch and bound method. The technique closes all network switches to create a meshed system, and switches are opened one by one to return to a radial configuration with minimal losses.

Shirmohammadi and Hong [6] produced a technique that started with a meshed network and opened the switches one by one following an optimal flow pattern. Goswami and Basu [7] consider Shirmohammadi and Hong's approach and improve the technique by closing one switch at a particular instant to introduce a mesh in the network. The network is returned to its radial configuration by analysing one loop at a time and opening a switch. Hsiao and Chien [8] developed a multi-objective method for optimal feeder reconfiguration to reduce losses that used a fuzzy satisfied method based on evolutionary programming and Hsu and Tsai also propose a multi-objective method based on evolutionary programming.

In this paper the proposed approach comprises of an algorithm for minimising losses that uses case base reasoning to identify the best solution to reconfigure the network. The algorithm also considers the effects that DG has on losses. This algorithm was tested on a sample distribution network and a smart grid demonstrator was constructed to illustrate how such a system might function in practice.

NETWORK ANALYSIS

In order for the algorithm to determine what actions are necessary at any one point, Case Base Reasoning (CBR) is applied. CBR allows for a case base to be populated with various network scenarios, and also for the case base to be updated as new solutions are developed. It is also possible to apply a weighting factor to the case search in CBR to enable the losses minimisation scheme to minimise the number of lines switched in or out in reconfiguration so that the network remains as close as possible to the original configuration for minimised switching.

To populate the case base a series of power flow simulations were run with different network configurations and with the DG operating at different outputs. Fig. 1 presents the network analysed. This analysis illustrated, as expected, that not all reconfigurations have a positive effect on losses.

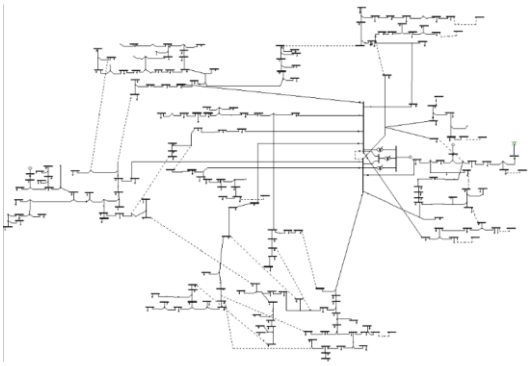

Figure 1 - Diagram of Simulated Distribution Network

Tables 1 and 2 show the results from the reconfiguration analysis and the DG analysis respectively.

Table 1 - Network Reconfiguration Data

Configuration	Total Generation (MW)	Total Load (MW)	% Loss
Standard	113.148	109.089	3.59
Reconfig.1	112.889	109.089	3.36
Reconfig. 2	112.805	109.089	3.29
Reconfig. 3	112.749	109.089	3.28
Reconfig. 4	113.139	109.089	3.58
Reconfig. 5	113.162	109.089	3.60
Reconfig. 6	113.157	109.089	3.59
Reconfig. 7	113.152	109.089	3.59
Reconfig. 8	113.149	109.089	3.59
Reconfig. 9	113.144	109.089	3.58
Reconfig. 10	112.910	109.089	3.38
Reconfig. 11	113.163	109.089	3.56
Reconfig. 12	112.889	109.089	3.36
Reconfig. 13	116.104	109.089	6.04
Reconfig. 14	113.138	109.089	3.58
Reconfig. 15	112.554	109.089	3.08

Table 2 - Optimised DG Data

Time	DG Output (MW)	Total Generation (MW)	Total Load (MW)	% Loss
1830	2.997 (+50%)	113.111	109.089	3.555

ACTIVE NETWORK MANAGEMENT SYSTEM

The ANM system consists of the developed losses minimisation algorithm and additional software and hardware required to implement it. This section describes these elements of the ANM system configured to demonstrate and test the losses minimisation approach.

Losses Minimisation Algorithm

The control actions that the algorithm was programmed to take are network reconfiguration and DG export control.

These control actions were selected for use in the algorithm as previous research has shown that both network reconfiguration and the use of DG can positively impact on losses in the right conditions. Bell et al [9] demonstrate the effects of DG on network losses. They found that at times of high demand, increasing DG output has a beneficial effect, however at periods of low demand DG should be set to a minimum. Fig. 2 illustrates the steps taken by the algorithm in a flow chart.

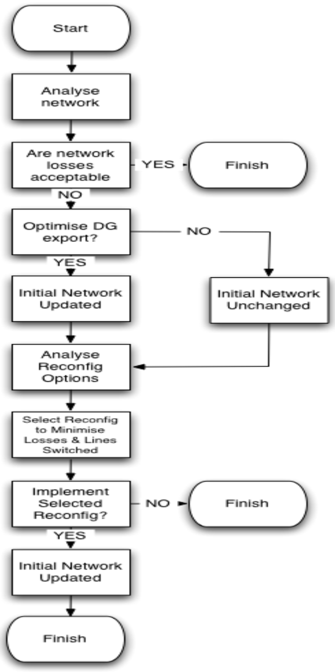

Figure 2 - Flow Chart of Losses Minimisation Algorithm

The steps of the algorithm are described as follows:

1. Acquire and analyse the initial network data
2. Calculate the losses in the network
3. Determine if losses could be reduced to a more acceptable level by reconfiguring network
4. If the losses are acceptable the algorithm stops
5. If the losses are not acceptable the option is given to alter the output from the DG
6. If the DG export is altered the network is re-analysed to calculate new losses with altered DG export
7. Three options for network reconfiguration are presented and analysed
8. The configuration with the lowest losses and lowest number of lines switched is recommended
9. If the DG export is not altered the algorithm presents and analyses three network reconfiguration options then goes to step 8.
10. The option to implement the suggested change is given and if chosen the reconfiguration is applied to the network

Smart Grid Demonstrator

Fig. 3 presents a block diagram of the ANM system. The Local Generator, Substation, Network and Control Room are linked over standard Ethernet LAN TCP links.

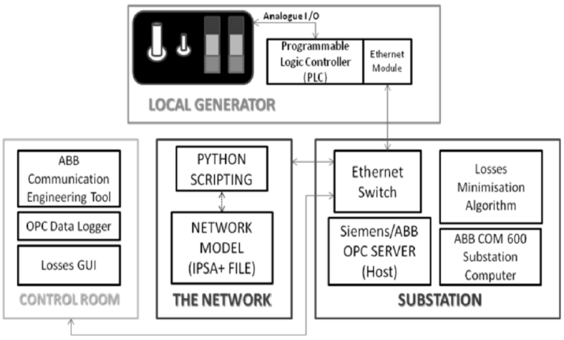

Figure 3- Block Diagram of ANM System

The electricity network is simulated by a software model with the current state of the network sent to the Substation Computer. In reality, the Substation Computer would be installed within the substation which receives all measurements from field devices. The algorithm is housed in the Substation Computer along with OPC servers which facilitate communication between the network (simulated in this case), Substation Computer and a Programmable Logic Controller (PLC) at the generator. An OPC server is a software application developed between Microsoft and the automation industry in a drive to create a software interface which allows real time automation data to be exchanged between Microsoft based clients and control systems. In this case the OPC server is created to transfer current network state data to the Substation Computer.

The DG real power level is simulated using an external analogue voltage signal from a control and display circuit box. The PLC acts as an interface and control signal actuator providing the demonstrator with a conduit to physical implementation and feedback.

The human interface for the developed algorithm would be viewed off-site in a control room by remotely accessing the Substation Computer. If actions are required they can be taken from the control room using functionality within the substation computer.

CASE STUDY: LOSS MINIMISATION

A typical domestic load profile [10] was applied to the network model. This is displayed in Fig. 4. A case study was carried out with the network fully loaded at approximately 6.30pm to show maximum impact from both reconfiguration and optimising DG.

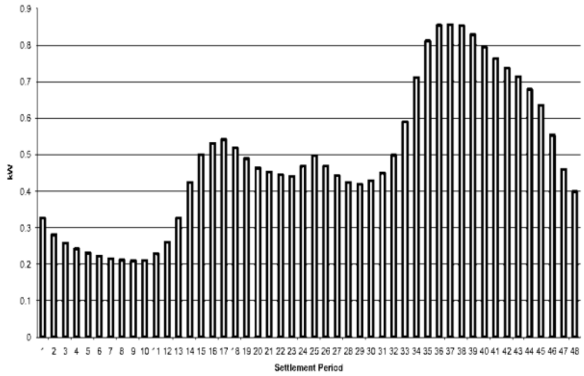

Figure 4 - Average Domestic Daily Load Profile

Upon starting the algorithm, the network is analysed in its initial state and Fig. 5 shows the data displayed by the analytical part of the ANM system. A value for the target losses in the network to act as a reference is chosen by the user before the network is analysed. If the losses in the network are above this value the algorithm states that the network requires attention.

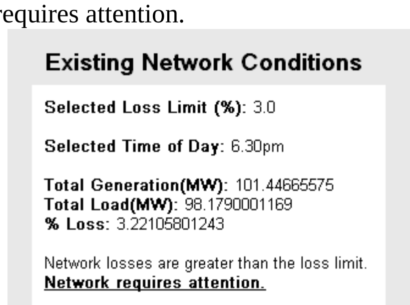

Figure 5 – User Interface Screen Displaying Initial Network Data

The user is then asked if they wish to alter the output from the DG to reduce losses. Fig. 6 shows the new network data with the DG running at maximum capacity.

Figure 5 – User Interface Screen Displaying Network Data with Optimised DG

With the DG running at maximum capacity the losses in the network are reduced. The losses reduction due to DG is small in this case: down from 3.22% to 3.19%. From here the user is asked if they wish to analyse three reconfiguration options to reduce losses further. This is achieved by running a power flow analysis on an offline model of the network with the current network status data. Fig. 7 shows the results of the analysis.

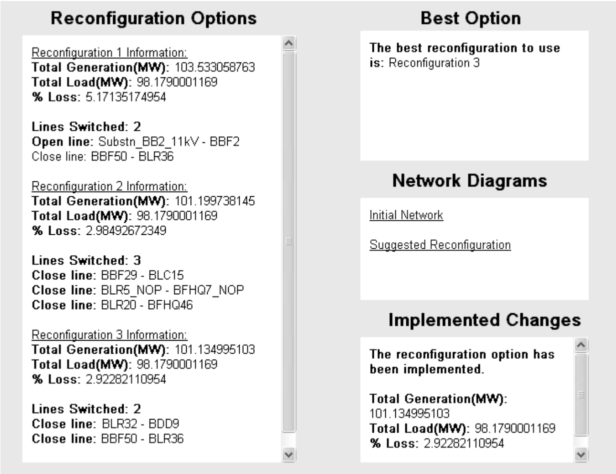

Figure 6 – User Interface Screen Displaying Reconfiguration Data

The algorithm displays the best option for reconfiguration based on the lowest losses and the lowest number of lines switched. In this specific case the line losses are further reduced to 2.92% in the best option (number 3) and two line switching operations would be required to achieve this outcome. The user is then able to choose whether to implement the option or not. If the reconfiguration is applied to the network, the network is analysed again and the data displayed to show that the change has been successful. The level of user interaction in this example implementation is higher than would be desirable in reality and automation of the decision processes and reduction of user interaction would be required for full implementation. Automating the decision processes would require users to state preferences relating to losses reduction targets and allowed switching sequences.

FURTHER WORK

Future developments that could be made and tested to the algorithm and system include increasing the case base to include a comprehensive set of reconfiguration options to enable identification of more than three reconfiguration options and more than one DG unit (as in the current example). In its current form, the algorithm analyses the network reconfiguration options offline which results in the algorithm being network specific. This could be overcome by using the live network model and data to perform an analysis of each valid reconfiguration option. The algorithm is also only capable of controlling one DG unit but it is envisaged that the algorithm and system will be developed further so that more DG units can be incorporated.

The algorithm can, in addition, be developed to include transformer tap changer control and electric vehicles as dispatchable storage. This would require a priority system to be employed as transformer tap levels regulate voltage levels so losses minimisation would be of lesser significance than meeting network voltage limits and constraints. The losses minimisation ANM system described in this paper was developed to expand the functionality of the smart grid functionality in a major research and demonstration activity at the author's research laboratories. The losses minimisation functionality is required to be developed further and integrated with the other smart grid functions in the laboratory based smart grid demonstration and then in a major network demonstration.

CONCLUSION

The developed losses minimisation algorithm was demonstrated to work as desired (against the specification) and successfully control elements in the network model to reduce the real power losses. The case study example illustrates, for a laboratory demonstration, the process for identification and implementation of minimum losses alternative network configurations and DG unit output set-points. However, there remains a range of adaptations and developments that can be made to the losses minimisation ANM system to significantly improve its operation and address the real needs for implementation and full network demonstration.

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