ANALYSIS OF MEDIUM AND LOW VOLTAGE DISTRIBUTION NETWORK WITH HIGH LEVEL PENETRATION OF DISTRIBUTED GENERATORS USING ERACS

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ABSTRACT

This paper analyses the technical impact of Distributed Generation on the Medium Voltage (MV) and Low Voltage (LV) Networks using ERACS specifically considering the changes in voltage profiles, real and reactive power flows caused by the introduction of small scale distributed generators(SSDGs) both at the medium voltage (MV) and low voltage (LV) levels of distribution networks**.**

Keywords: Distributed Generetors,Voltage profile, Three phase fault levels, Power distribution system.

1.0) Introduction

Distributed generation also known as small scale electricity generation is quiet recent in litratures about the economies of electricity markets, the early days of electricity generation it was a rule not an exception. The first power plants which were DC based, only supplied power to nearby customers in close neigbourhood of the close power generating station. Balancing demand and supply was done using local storage which could be directly coupled to the DC grids (G. Pepermans etal., 2005).

Technological evolutions which has resulted in modern electrical power systems have traditionally been designed to match the template of large central generating units all interconnected via high voltage transmission networks. The power is then transmitted over long distances & unto distribution networks enroute the final consumers via transformers (OECD/IEA, 2013). This arrangement has a number of advantages pertaining to network efficiency, voltage & frequency control, spinning reserves & generator dispatch and the reduction of losses through high voltage transmission. Distribuited generation arose and has continued to develop from the needs to minimise losses incurred via transmission, efficiently harness the available energy via other modes of power generation and most recently to benefit from several generation incentives on offer by various European and world governments in their aims to cut emission levels and improve energy security (US.DOE, 2007). At present there is no universally agreed definition of what constitutes distributed generation. However the following are commonly cited as properties (Felix, 2006).

- Normally smaller then 50-100MW
- Not centrally planned or dispatched (by the utility)
- Usually connected to the distribution system

As with all deviations from conventional processes, Distributed generation within the already existing distribution network (which being a passive network is designed to pass power down voltage levels to LV customers) brings about its own unique problems and challenges. One of the most prominent of these is its effect on voltage profile. In the UK, voltages between 1-132 KV should be maintained at ±6% of the nominal voltage & at +10 to -6% for systems between 50V – 1000V. this variation used to be ±6% for the 50V-1KV range prior to the 1994 amendments made to harmonise the UK electricity system with the rest of Europe (Jenkins, 2000). The onus falls upon the distribution network operator (DNO) to ensure its systems are operated within the limits permitted by the electricity supply regulations (Butler, 2001).

For the purposes of safety, efficiency and network relaibility and security, network operators have to carry out studies prior to the connection of distributed generators as there exist several technical issues that must be considered such as

- System fault levels
- Reverse power flow capability
- Voltage rise
- Losses
- Voltage rise
- Protection (people, personel, equipment e.t.c)
- System stability

At present the technical and seasonal characteristics & shortcomings of most popular forms of distributed generation limits their use to the provision of energy and not the other functions of the power system e.g voltage control, network reliability, generation reserve capacity , e.t.c (D.H. Popovic, 2005).

There are a number of technical impacts that need to be considered with respect to the connection and operation of small scale distributed generators (SSDGs) on public LV networks which has to do with centralised and decentralised renewable energy sources (Alessandra Parisio etal., 2014). The change in voltage profiles and real and reactive power flows caused by the introduction of SSDGs has important implications both at the LV levels of distribution networks, as well as the MV levels through distribution transformers (Trichakis P, 2008), some of the technical impacts are Network voltage changes, Power quality, Increase in network fault levels, Stability and protection issues (B. Du Pont etal., 2014).

2.0) Challenges of Increased Penetration of Distributed Generators

There are lots of challenges which has to do with the increase of the penetration of distributed generators into the MV and LV networks which can be classified into technical, commercial and regulatory (J.A. Pecas Lopez etal., 2007). The focus of this paper is on the technical issues which are Voltage rise, protection, Power quality and stability.

2.1) Voltage Rise

This effect on its own, limits the amount of additional distributed generators that can be connected to the medium and low voltage distribution network.

2.2) Protection

This technical issue can be classified as 1.) Protection of the generators from internal faults 2.) Protection of the faulted distributed network from fault currents supplied by the distributed generators. 3.) Loss of mains protection which can be experienced as one of the impact of the DG's on an existing distribution network protection.

2.3) Power Quality

The quality of power is actually related to two important aspects which are the harmonic distortion of the voltage networks and transient voltage variation. The DG's can either decrease or increase the quality of the voltage received by the end users of the distribution network depending on the

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situation (Keane 2007). The effect of increasing the network fault level by adding DG's often leads to improved power quality but it is important to note that large DG's when connected to a weak network can lead to poor power quality.

2.4) Stability

Normally stability issues are not considered in the design of a distribution network as the network is passive and remains stable under most circumstance provided the transmission network is stable (J.A. Pecas Lopez etal., 2007). Stability is also not an issue when assessing renewable distribuited generation schemes but as the penetration of the DG's increase their contribution to the network security increases as well and voltage collapse, transient and dynamic stability becomes an issue (Marija IIic 2007).

3.0) Simulation Details

This paper takes into consideration the simulation of a Meduim voltage network with ten (10) bus bars and a low voltage network with seven (7) bus bars considering maximum and minimum load with high penetration of distributed generators. The distributed generators are intigrated at 11.5KV and 415V level, the grid generates about 22.5MW at 33KV with stepdown transformers converting the 33KV to 11.5KV for the medium voltage distribution network with ten (10) bus bars and a 11.5KV/415V transformer feeding the low voltage distribution . When the distributed generators is to be connected to the MV or LV network, prior notification must have been given to the distribution network operators (DNO) who in turn carry out studies to determine the viability and limits of the new generation. Worst case scenario tests are carried out to ensure that the network & customers will not be adversely affected.

For the purposes of this of this paper, the following four scenarios are considered and simulated

- Maximum load condition without distributed generators
- Minimum load condition without distributed generators
- Maximum load condition with 100% penetration of distributed generators
- Minimum load condition with 100% penetration distributed generators

Maximum and minimum load per customer are respectively given as 1.4 & 0.2 KVA with a suggested distributed generator rating of 1.1 KVA per customer. Practically, distributed generation takes several forms from diesel generators, wind turbines, PV solar ,CHP generation, reciprocrating machines, fuel cells e.t.c so to make this simulation as practical as possible both induction and synchronous generators will be modelled and simulated in the network. The theoretical mix of 40% induction generation and 60% synchronous for the initial stages using a generator power factor of 0.8 all through.

After each simulated scenario, load flow analysis was carried out with emphasis placed on the flow of power, the fault levels and voltage profiles of each scenario and the relevant graphs were plotted for analysis and commentary. Under this initial condition it was found that the voltage profile for the minimum load, maximum generation condition (worst case scenario) did not satisfy the standards set by regulation and adjustments were made to correct this. To do this the limit of penetration of the distributed generators had to be found and set.

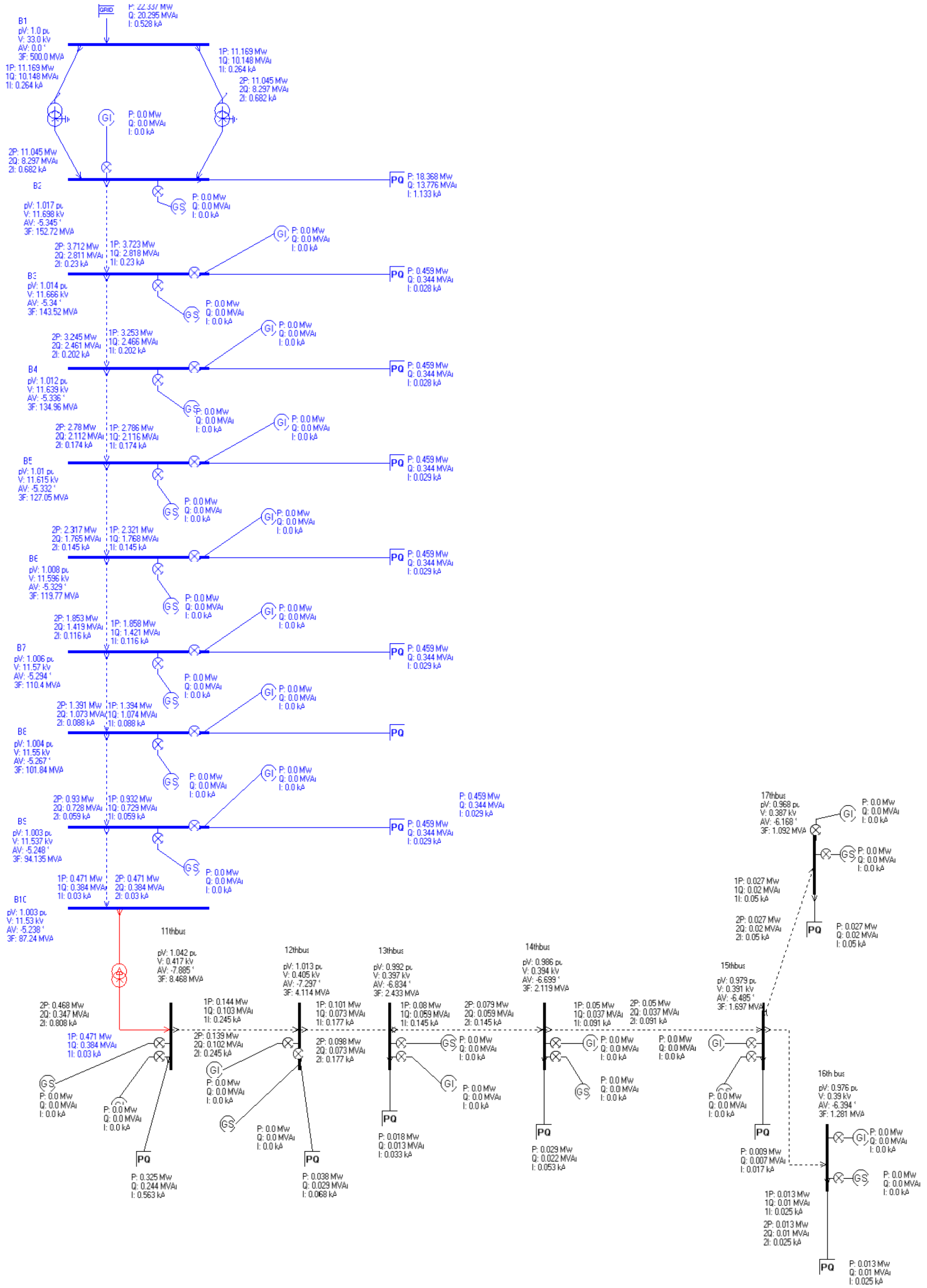

Fig1: Maximum load simulation without distributed generator

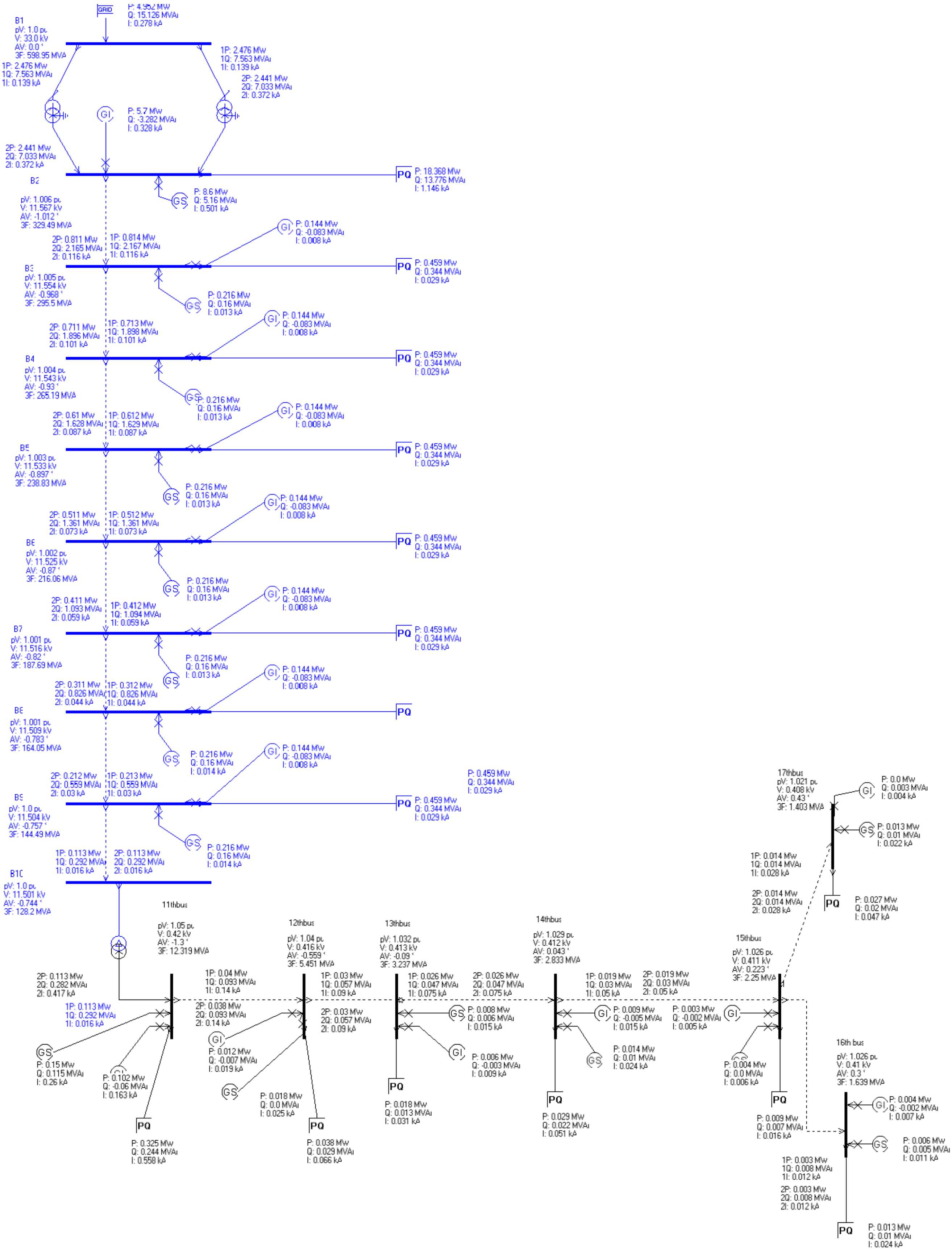

Fig 2: Maximum load simulation with 100% penetration distributed generation

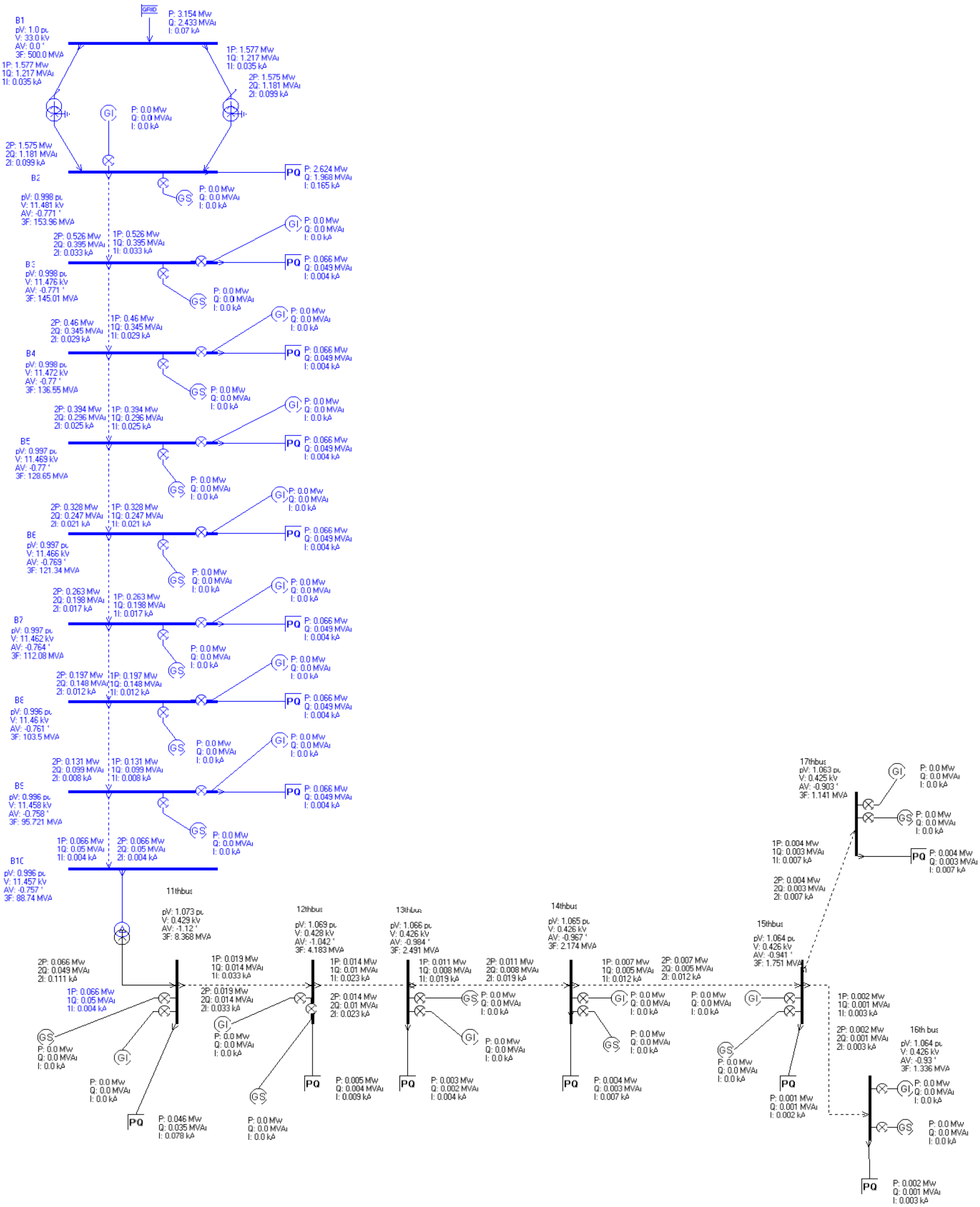

Fig 3: Minimum load simulation without distribution generator (0% penetration)

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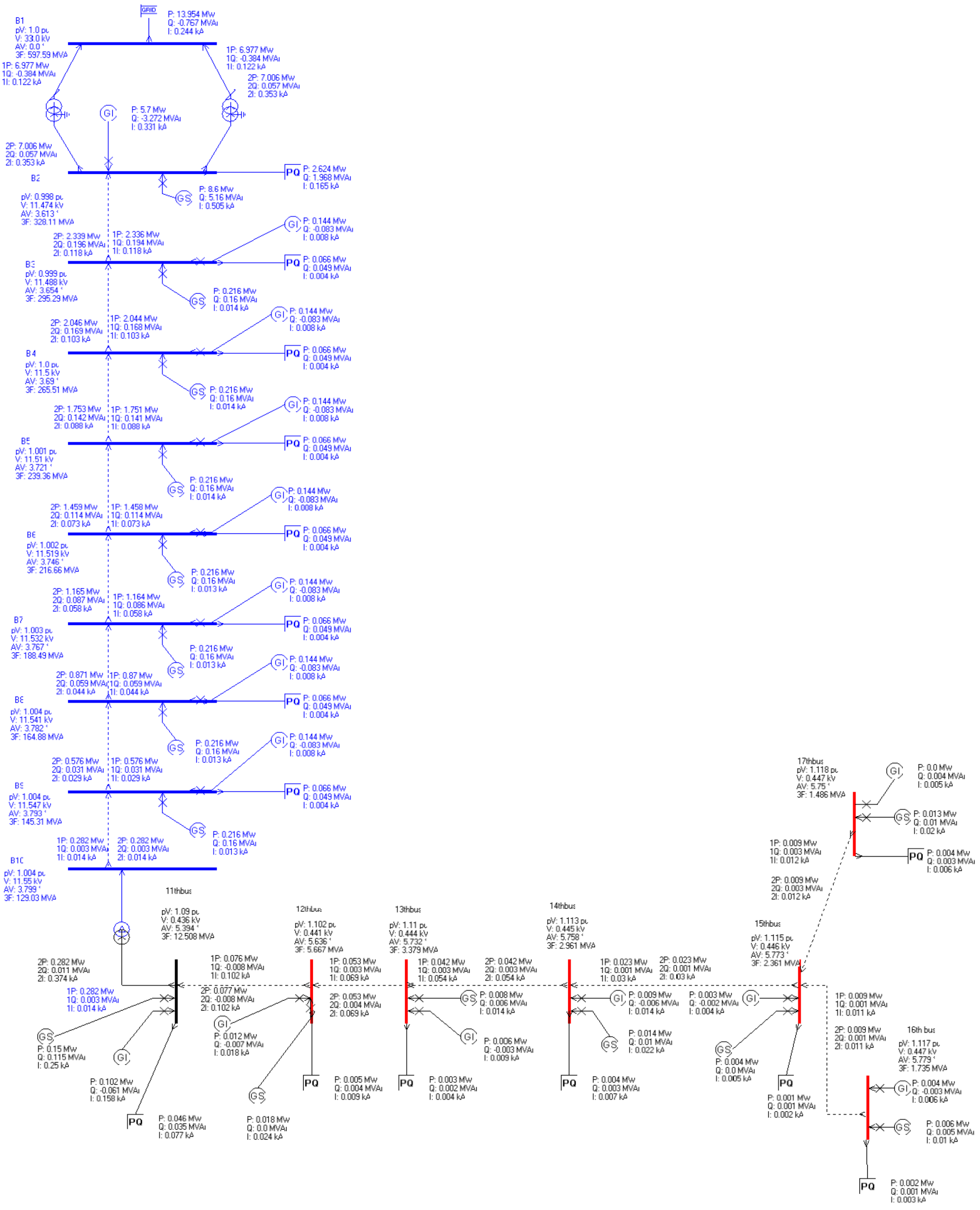

Fig 4: Minimum load simulation with (100% penetration) distributed generators

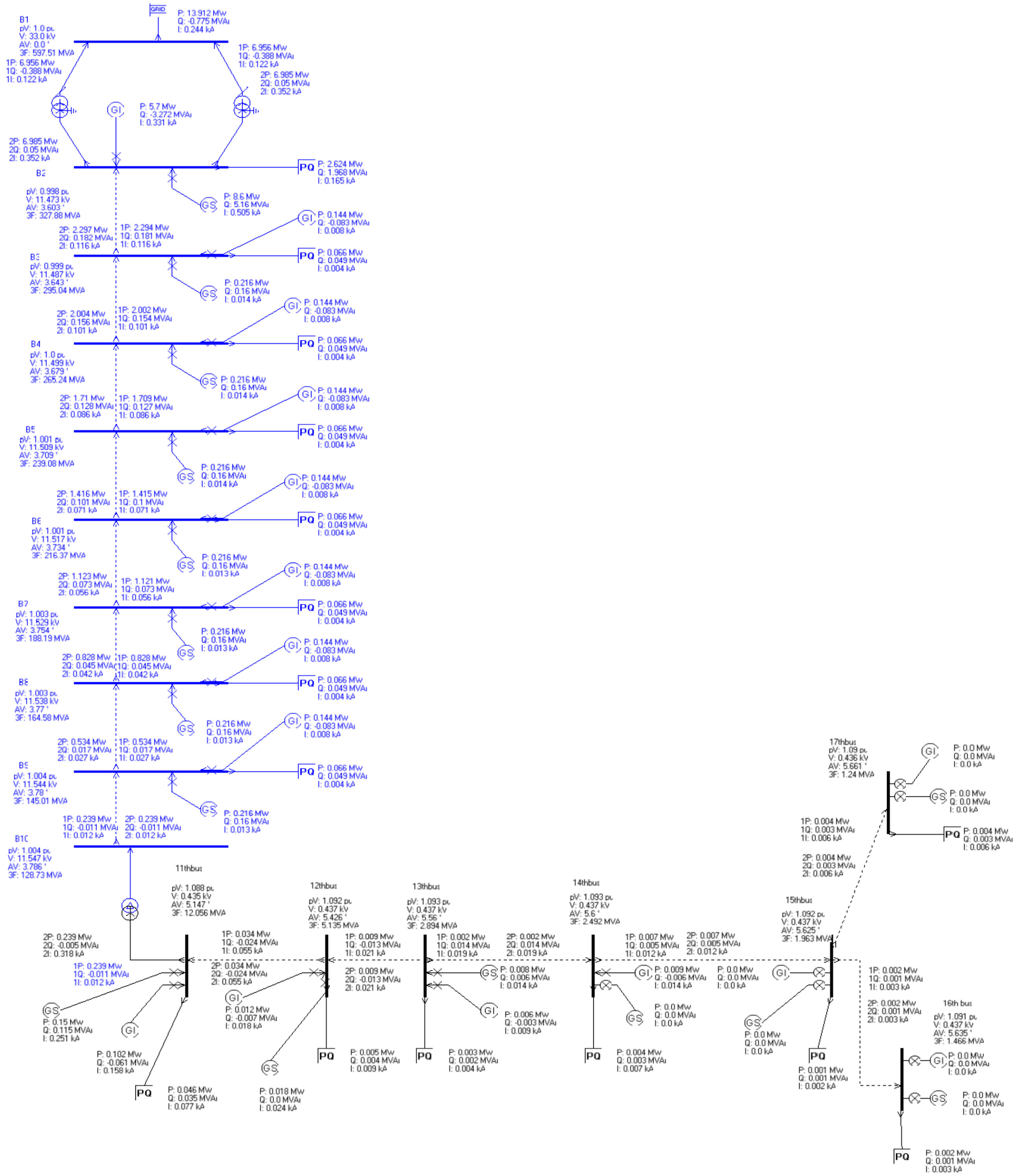

Figure 5: Minimum load simulation with (96% penetration) embedded generation

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4.0) Results

This section contains the tables and resulting graphical plots and from the simulations. Plots & comments of the voltage profile for all simulated scenarios are shown first followed by those for fault levels.

Busbar ID	pV (Per Unit with 100% penetration of Distributed Generators)	pV (Per Unit without Distributed Generators)
B1	1	1
B2	1.005847	1.017186
B3	1.004714	1.014462
B4	1.003722	1.012073
B5	1.002868	1.010022
B6	1.002154	1.008307
B7	1.001358	1.006054
B8	1.000756	1.004357
B9	1.000346	1.003216
B10	1.00013	1.002633
B11	1.050318	1.041694
B12	1.039576	1.013275
B13	1.031604	0.991824
B14	1.029254	0.985744
B15	1.026366	0.978704
B16	1.025592	0.975734
B17	1.021059	0.968436

Table 1: Result for Load Flow Analysis Carried out in ERACS showing the Voltage Level for Maximum Load Condition

Busbar ID	pV for minimum load condition with 100% penetration embedded generation (pu)	Pv for minimum condition without embedded generation (pu) (0% penetration)	pV (pu) for minimum load condition with 96% penetration
B1	1	1	1
B2	0.997736	0.998322	0.997676
B3	0.998937	0.997931	0.998851
B4	0.999985	0.997589	0.999874
B5	1.000881	0.997295	1.000745
B6	1.001625	0.997051	1.001464
B7	1.002743	0.99673	1.002537
B8	1.003575	0.996489	1.003325
B9	1.004123	0.996328	1.003828
B10	1.004386	0.996247	1.004046
B11	1.08998	1.072562	1.087704
B12	1.101689	1.068812	1.091958
B13	1.110467	1.066	1.092914
B14	1.112857	1.065204	1.092573
B15	1.115446	1.064287	1.091679
B16	1.116955	1.063898	1.0913
B17	1.118188	1.062952	1.090378

Table 2: Result for Load Flow Analysis Carried out in ERACS showing the Voltage Level for Minimum Load Condition

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Busbar ID	3F (MVA) Max load without DGs	3F (MVA) Max load with DGs
BUS-0001	500	596.183
BUS-0002	151.422	311.201
BUS-0003	101.409	170.603
BUS-0004	76.15	121.454
BUS-0005	60.897	95.817
BUS-0006	50.675	79.541
BUS-0007	49.354	77.41
BUS-0008	48.001	74.908
BUS-0009	46.63	72.105
BUS-0010	45.255	69.069
BUS-0011	7.672	11.487
BUS-0012	3.926	4.867
BUS-0013	2.369	2.812
BUS-0014	2.072	2.448
BUS-0015	1.687	1.965
BUS-0016	1.685	1.963
BUS-0017	0.401	0.466

Table 3: Result for Load Flow Analysis Carried out in ERACS showing the Fault level comparison for maximum load conditions

Busbar ID	3F (MVA) Min load without DGs	3F (MVA) Min Load with DGs
BUS-0001	500	591.171
BUS-0002	153.823	307.232
BUS-0003	100.494	166.393
BUS-0004	74.605	118.066
BUS-0005	59.311	93.057
BUS-0006	49.212	77.262
BUS-0007	48.006	75.293
BUS-0008	46.778	72.985
BUS-0009	45.539	70.398
BUS-0010	44.302	67.592
BUS-0011	7.556	11.484
BUS-0012	4.03	5.013
BUS-0013	2.45	2.909
BUS-0014	2.146	2.535
BUS-0015	1.753	2.041
BUS-0016	1.741	2.025
BUS-0017	0.322	0.376

Table 4: Result for Load Flow Analysis Carried out in ERACS showing the Fault level comparison for minimum load conditions

5.0) Voltage Profile Plots

The onus falls on the DNO to ensure that voltage values at all points along a feeder line fall within the ranges stipulated by the regulations authority. Hence the need for studies prior to the connection of further loads and generation especially those feeding into the lower voltage lines as is usually the case with DG's in the UK & for this paper the acceptable p.u voltage range is 1.1 and 0.94 for the upper and lower limits respectively.

In practical terms DNOs are mostly interested in knowing what happens under worst case conditions. This is when distributed generation is at a maximum and load demand is at a minimum. As can be seen from the profile plot for maximum load scenario (figure 5), the resulting voltage levels at all points along the line is well within acceptable limits. The voltage is boosted at points B2 & B10 due to the effects of the transformers and tap changers and is seen to drop along the line due to the effects of line loading. However, with and without differing levels of embedded generation the voltage range is still satisfactory for the maximum load conditions.

During minimum load scenarios, the effect of line loading doesn't compensate for the ineveitable voltage rise and there is always the tendency for voltages to go beyond acceptable limits. As is seen from figure 6, low loading of the line does not bring about a significant drop in voltage along the 11KV and 0.4KV lines for both 0% & 100% DG penetration. However with a 100% penetration the voltage along the 0.4KV line from points B12 to B17 rises above the 1.1 p.u mark and is deemed unacceptable. To maintain adequate values under the existing loading condition an acceptable penetration value had to be found and 96% penetration value was deemed as the upper maximum limits under minimum load condition. Figure 7 shows the resulting plot of this revision.

It should also be noted that the voltage profile doesn't exhibit a voltage boost at point B2 as in the case of maximum load. This is because of the proximity of a DG to transformer. It influneces tap-changing because the DG infeed decreases the resulting load for the transformer.

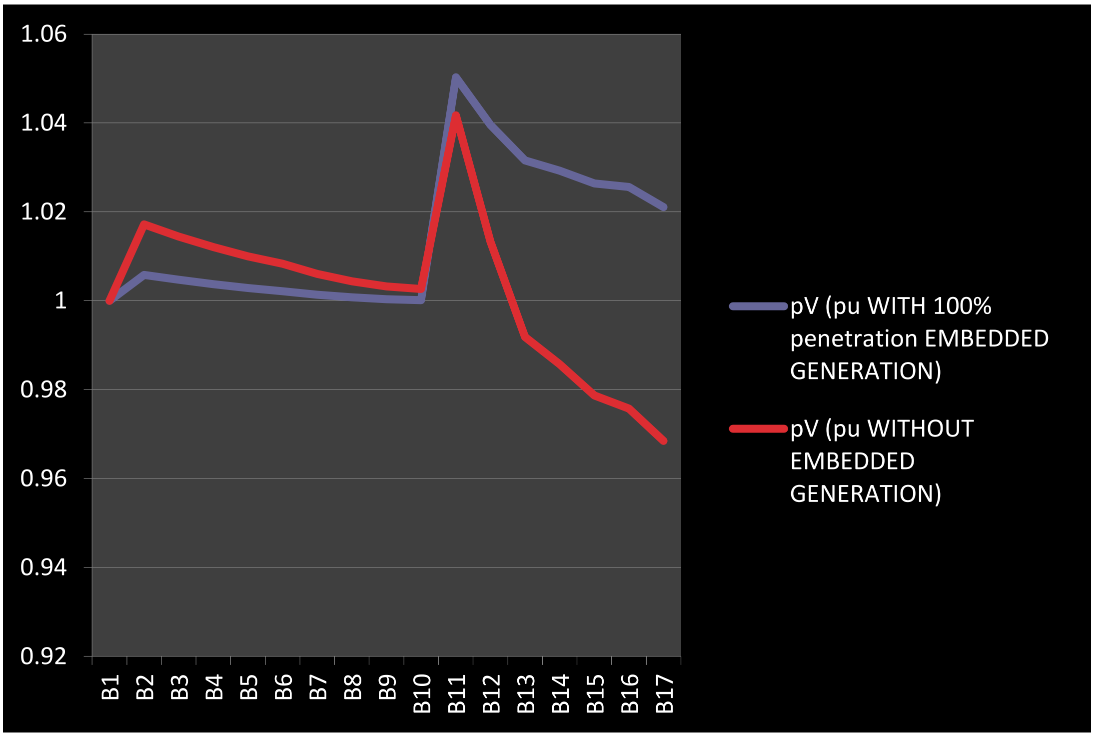

Fig 5: Plot showing Voltage profile comparison for maximum load conditions from Table 1

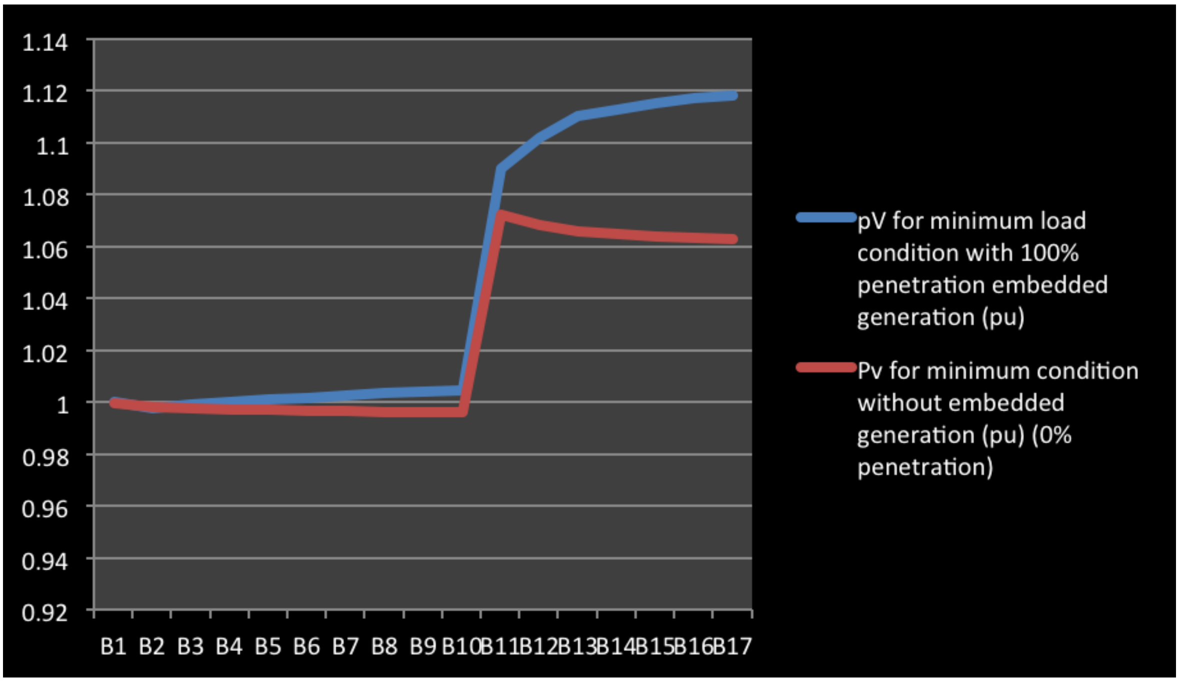

Fig 6: Voltage profile comparison for minimum load condition from Table 2

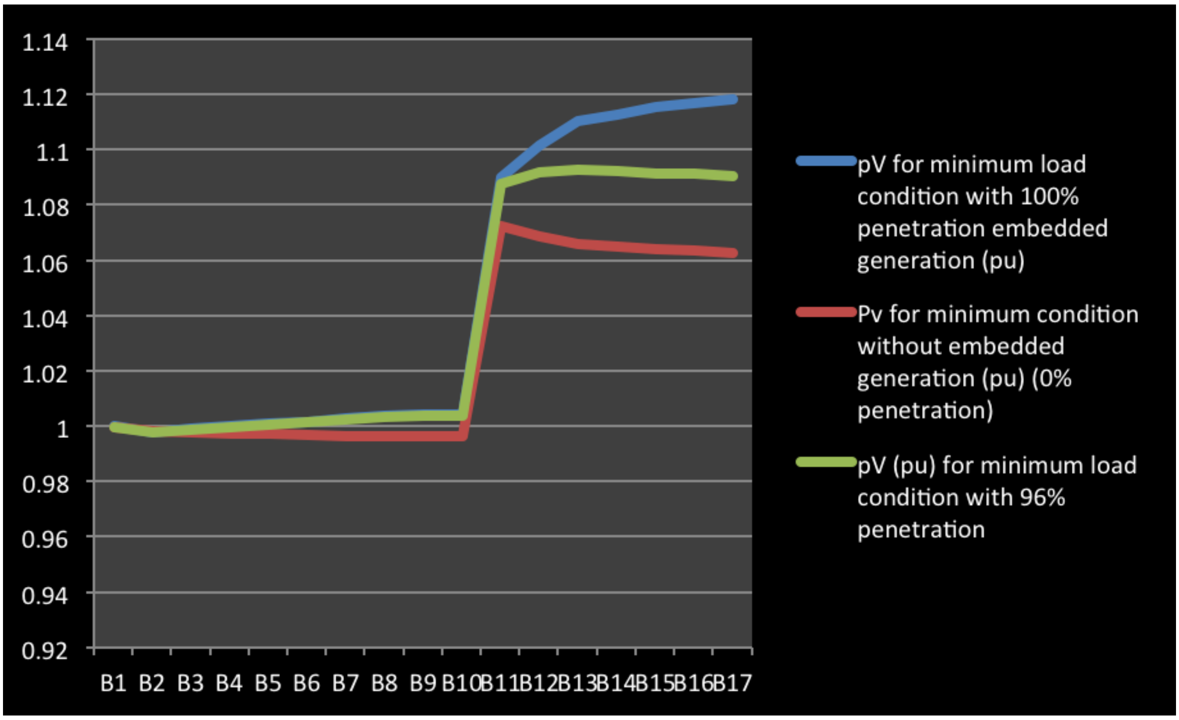

Fig 7: Voltage profile plot for minimum load scenarios showing revised penetration values for Distributed Generation from Table 2

6.0) Fault Level Plots

A network's total fault level is roughly an estimate of the combined short circuit contribution of the upstream grid and various other sources within the distribution system. Apart from keeping within the acceptable voltage range, a basic requirement for the connection of DG is to ensure that the resulting fault level remains below the network design value under the most unfavourable conditions (Jenkins N., 2010).

Distribution networks are not designed to accept large amounts of DG because their short circuit capacity is already close to design maximum value. The upgrading of protective devices to raise the network fault level is an expensive exercise and under the present UK law it is the responsibility of the DG operator so the first point of call is to limit the contribution of the DG to fault levels. This is achieved using different methods

1. Increasing the short circuit impedance of the HV/MV transformer.
2. Utilising reactors and short circuit limiting devices at the DG level. However note must be made of the effect of these factors on losses.

Analysis of the fault level plots for both minimum and maximum load scenarios (figures 8 & 9) shows that the fault level has risen by around 100MVA and that the increase is most prominent in the 11.5 KV section of the network and mostly unchanged in the lower voltage range.

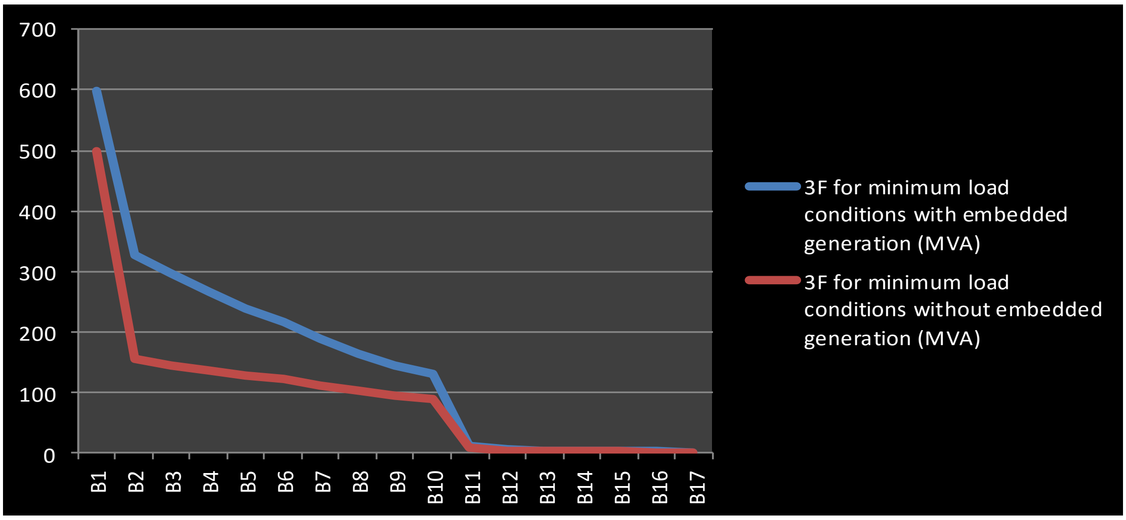

Fig 8: Fault level comparison for minimum load conditions

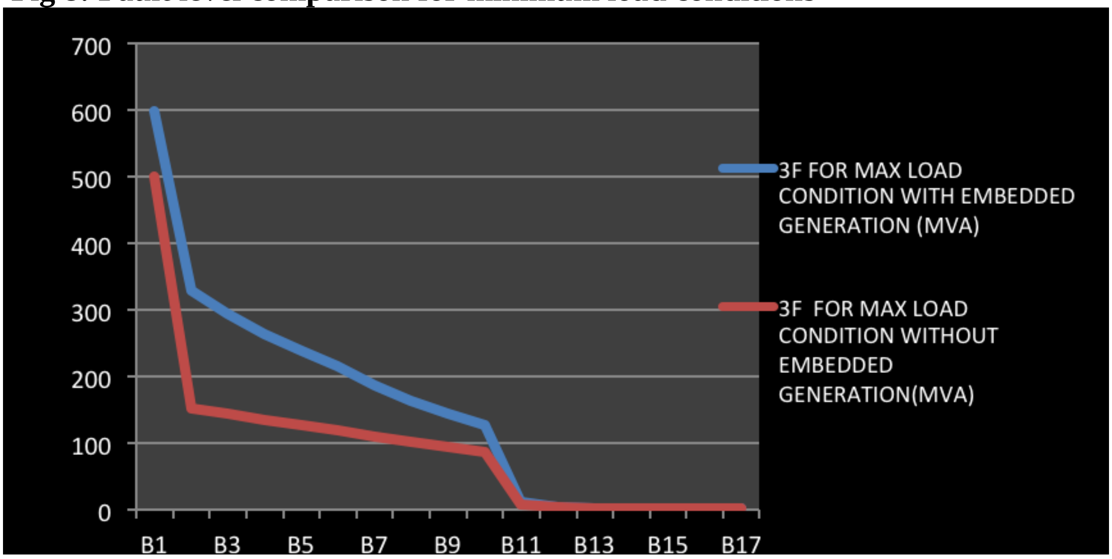

Fig 9: Fault level comparison for maximum load conditions from Table 3

7.0) Load & Power Flow Analysis and Further Critical Discussion

The maximum load scenarios are used to exhibit an advantage of distributed generation as regards losses within the system. Losses due to transmission are inevitable. By supplying the power required closer to the point of need, DGs eliminate losses that would have accrued due to transmission and heating effects of the power flowing long distances in the cables.

For maximum load scenario with 0% penetration
PL =22.04MW, PG=22.337MW, QL=16.529MVAr, QG=21.552MVAr giving a real power loss of 0.297MW and a reactive power loss of 3.76 MVAr.
At 100% penetration PL=15.196, PG=15.277, QL=20.474MVAr, QG=21.552MVAr resulting in a real power loss of 0.081MW & reactive power loss of 1.078MVAr

Where PL, PG, QL & QG stands for Load real power, Generated real power, load reactive power and generated reactive powers respectively. It can easily be seen that distributing generators into the system have resulted in real power savings of 0.216MW and reactive power savings of 2.682Mvar.

8.0) Reverse Power Flow

Radial distribution networks are usually designed for unidirectional power flow, from the in feed downstream to the loads. This assumption is reflected in standard protection schemes with directional overcurrent relays. when local production exceeds consumption, power flow changes direction as can be seen from the simulated scenarios (figures 4 & 4b) for the minimum load conditions. Network operators must ensure that sensitive equipment and protective devices are capable of handling reverse flows of power in the network. In particular the tap-changing characteristics of the transformers must not be negatively impacted upon by the reverese flow of power through them.

It must be noted that different generators have their own unique characteristics and there exist a whole lot of types and configurations for embedding generators within a network (Thomas Ackermann 2001). Therefore the simulated scenarios are for this network alone using the previously mentioned generator mix. It should also be noted that the minimum load scenario simulated for this paper where a period of maximum generation coincides with minimum load demand is highly unlikely to occur in real life terms due to the residential nature of the loads and the high unlikely hood that all simulated PV arrays and wind turbines will be operating at maximum rating.

Also, apart from the potential benefit of reduced power losses in the system, the DNO also benefits from the postive effect of the distributed generators. As can be noticed from the simulation for maximum load, the 11.5KV/400V transformer works at overload rating during periods of max demand and 0% penetration. Depending on the length of time that this scenario lasted, the DNO might have had to replace the transformer with one of larger rating incurring costs. With the DGs supplying power directly into the LV feeder, less power is demanded through the transformer hence keeping its operation within rated range

9.0) Conclusion

Studies into distributed generation and their effects on the existing network that they are incorporated into are extremely important for the issues of stability, economics and safety of personel and the public at large. Present fault levels have been found to be extremely overrated though DNO's must continue to run simulations and tests to ascertain the limits of safety required to embed generators.

In incorporating the high level distributed generators to the low voltage distribution network, 100% penetration is considered (50% from synchronous generators and 50% from induction generators) to obtain a voltage profile within limits. The system is designed to operate within limits for maximum load with small scale distributed generators (SSDGs) and to supply excess power to the grid at minimum load with the SSDGs (reverse power flow), this calls for effective power flow management, because the flow of power in a distribution network is normally designed to be unidirectional from higher to lower voltages, but the introduction of high level distributed generation will cause power to flow in both directions, under these circumstances, network assets are at risk of being operated above their rating but in the above I have considered under exciting some of the synchronous generators so as to avoid the risk.

In the overall the incorporation of high level distributed generation to a low voltage distribution network has more advantages than disadvantages.

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