

The Effect of Distributed Generation on Power System Protection

by

Mohamed Talal Mohamed Elmathana

Presented to the University of Exeter

As a thesis for the degree of Masters by Research

In Renewable Energy

September 2010

This thesis is available for Library use on the understanding that it is copyright material and that no quotation from the thesis may be published without proper acknowledgement.

I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

(signature)

Abstract

Interconnecting a distributed generation (DG) to an existing distribution system provides various benefits to several entities such as the DG owner, utility and end users. DG provides an improved power quality, higher reliability of the distribution system and covering of peak shaves. Penetration of a DG into an existing distribution system has so many impacts on the system, despite the benefits a DG will provide; it has a negative impact on one of the most important aspects of the system which is the power system protection, and it is a main factor affecting both reliability and stability of the system. DG causes the system to lose its radial power flow, besides the increased fault level of the system caused by the DG. In this thesis, the effect of DG penetration on the short circuit level of the network is investigated through simulating the IEEE 13 bus test feeder using **ETAP**. The simulation is repeated for nine different cases at which the location of one large DG is changed in six of the cases to study the effect of the distance on the fault level, while the rest of the cases are performed using small decentralised DGs. The result of those three cases at which the DG is decentralised are used to investigate the effect of the generating capacity of the generation unit on the distribution network parameters and on the currents flowing through the laterals of the distribution network. Results are compared to that of the normal case to investigate the impact of the DG on the short circuit currents flowing through different branches of the network to deduce the effect on protective devices.

Acknowledgements

I would like to express my deep gratitude to my supervisors, Dr. Ahmed F. Zobaa and Prof. George Smith for their great support throughout my research. I sincerely appreciate their continuous encouragement.

Special thanks to Dr. Hatem Zeineldin at MASDAR Institute of Science and Technology for his great technical support and his continuous useful advice that helped me to finish this work.

I want to take this opportunity to thank my parents for everything they have done to me and their precious advice through my life. Dr. Talal M. Elmathana my father, however I express my thanks, it will never fulfil your grant. Finally I would like to thank my wife for her effort and encouragement throughout my research period.

Table of Contents

Abstract	2
Acknowledgements	3
Table of Contents	4
List of Figures	6
List of Tables	8
List of Symbols and Abbreviations	13
Chapter 1: Introduction	15
1.1 Brief Introduction	15
1.2 Thesis Objectives	18
1.3 Thesis Structure	18
1.3.1 Outlines	19
Chapter 2: Literature Review	21
2.1 Introduction.....	21
2.2 Types of Distributed Generation [1]-[5].....	21
2.2.1 Photo voltaic.....	21
2.2.2 Wind Turbines.....	22
2.2.3 Fuel Cells.....	22
2.2.4 Micro-Turbines	22
2.2.5 Rotating Machines	23
2.3 Impact of Distributed Generation on Power System Grids.....	23
2.3.1 Impact of DG on Voltage Regulation.....	23
2.3.2 Impact of DG on Losses	25
2.3.3 Impact of DG on Harmonics.....	26
2.3.4 Impact of DG on Short Circuit Levels of the Network.....	27
2.4 Interconnection Protection.....	28
2.5 Islanding of a Power Network	29
2.5.1 Islanding Detection	30
2.6 Impact of DG on Distribution Feeder Protection.....	31
2.6.1 Sympathetic Tripping.....	32
2.6.2 Reduction of Reach of Protective Devices.....	33
2.6.3 Failure of Fuse Saving Technique Due to Loss of Recloser-Fuse Coordination.....	34

Chapter 3: Simulation of IEEE 13 Bus with Different DG Configurations	38
3.1 Introduction.....	38
3.2 IEEE 13 Bus Test Feeder.....	38
3.2.1 Load Models.....	39
3.2.2 Over Head Lines	40
3.2.3 Transformers	41
3.2.4 Shunt Capacitor Banks.....	42
3.3 Cases Studied and Simulation Results	42
3.3.1 System Under Study	42
3.3.2 Case 1: IEEE 13 Bus without DG	44
3.3.3 Case 2: IEEE 13 Bus with 1*8 MW DG Located at bus 632.....	49
3.3.4 Case 3: IEEE 13 Bus with 1*8 MW DG Located at bus 634.....	53
3.3.5 Case 4: IEEE 13 Bus with 1*8 MW DG Located at bus 671	58
3.3.6 Case 5: IEEE 13 Bus with 1*8 MW DG Located at bus 675	62
3.3.7 Case 5: IEEE 13 Bus with 1*8 MW DG Located at bus 680.....	67
3.3.8 Case 7: IEEE 13 Bus with 4*2 MW DG's Distributed at Different Locations in the Network.....	71
3.3.9 Case 8: IEEE 13 Bus with 4*2 MW DG's Distributed at Different Locations in the Network.....	77
3.3.10 Case 9: IEEE 13 Bus with 5*2 MW DG's Distributed at Different Locations in the Network.....	83
3.4 Discussion.....	88
Chapter 4: Conclusion and Future Work.....	106
4.1 General Review.....	106
4.2 Conclusions Based on the Simulation.....	106
4.3 Future Work.....	107
Appendix: Coordination of Directional Overcurrent Relays to Prevent Islanding of Distributed Generators.....	108
REFERENCES.....	125

List of Figures

FIG. 2.1: ILLUSTRATING THE DG UNIT INTERFERENCE WITH VOLTAGE REGULATION IN A DISTRIBUTION FEEDER. LINE DROP COMPENSATION MUST BE EMPLOYED AT THE LTC CONTROL TO RESULT IN THE INDICATED VOLTAGE PROFILES. [6]	24
FIG. 2.2: A TYPICAL SYMPATHETIC TRIPPING SITUATION	33
FIG. 2.3: REDUCTION OF REACH OF R1	34
FIG. 2.4: PART OF A DISTRIBUTION NETWORK INCLUDING RECLOSER, FUSE AND BREAKER.	35
FIG. 2.5: NETWORK AFTER ADDING DG.....	35
FIG. 2.6: COORDINATION BETWEEN RECLOSER,FUSE AND CIRCUIT BREAKER[25].	36
FIG.3.1: ILLUSTRATING THE IEEE 13 TEST FEEDER [26]	39
FIG.3.2: OVER HEAD LINE SPACING. [27]	40
FIG.3.3: IEEE 13 BUS SYSTEM UNDER STUDY.....	43
FIG.3.4: CONFIGURATION USED IN CASE 7	72
FIG.3.5: CONFIGURATION USED IN CASE 8.....	78
FIG.3.6: FAULT CURRENT AT DIFFERENT FAULT LOCATIONS FOR CASE 1.	88
FIG.3.7: COMPARISON BETWEEN CASE 1 AND CASE 2	89
FIG.3.8: COMPARISON BETWEEN CASE 1 AND CASE 3	90
FIG.3.9: COMPARISON BETWEEN CASE 4 AND CASE 1	91
FIG.3.10: COMPARISON BETWEEN CASE 5 AND CASE 1	92
FIG.3.11: COMPARISON BETWEEN CASE 6 AND CASE 1	92
FIG.3.12: COMPARISON BETWEEN CASE 7 AND CASE 1	93
FIG.3.13: COMPARISON BETWEEN CASE 1 AND CASE 8	94
FIG.3.14: COMPARISON BETWEEN CASE 1 AND CASE 9	95
FIG.3.15: COMPARISON BETWEEN FAULT CURRENTS FOR ALL CASES	96
FIG.3.16: ILLUSTRATING THE POSSIBILITY OF FUSE BLOWING	98
FIG.3.17: FAULT CURRENT IN BRANCH FROM BUS 650 TO BUS 632.....	100
FIG.3.18: SHORT CIRCUIT CURRENT FLOWING IN BRANCH FROM BUS 632 TO BUS 671 IN ALL CASES WITH DIFFERENT FAULT LOCATIONS	102
FIG.3.19: FAULT AT BUS 632 WITH DG AT BUS 632.....	103
FIG.3.20: FAULT AT BUS 671 WITH DG AT BUS 632	104
FIG.A.1. A RADIAL DISTRIBUTION SYSTEM WITH TWO DISTRIBUTED GENERATORS INTERCONNECTED.....	112
FIG.A.2 A RADIAL DISTRIBUTION SYSTEM WITH DISTRIBUTED GENERATORS INTERCONNECTED AT BUS 2.....	116

FIG. A.3. A SIMPLIFIED RADIAL DISTRIBUTION SYSTEM WITH DISTRIBUTED GENERATORS INTERCONNECTED AT BUS 2.....	117
FIG. A.4. EFFECT OF THE DG MVA RATING ON THE RELAY OPERATING	119
FIG. A.5. EFFECT OF THE DG LOCATION ON THE RELAY OPERATING TIME.....	120
FIG.A.6. A RADIAL DISTRIBUTION SYSTEM WITH TWO DISTRIBUTED GENERATORS INTERCONNECTED.....	120

List of Tables

TABLE 2.1: MAXIMUM HARMONICS VOLTAGE DISTORTION FOR DISTRIBUTED GENERATORS AS PER IEEE 1547-2003. [7]	27
TABLE 3. 1: LISTING THE LOAD MODELS [27].....	39
TABLE 3.2: EXPRESSING SPOT LOAD CONFIGURATION IN IEEE TEST FEEDER [26].....	40
TABLE 3.3: LISTING THE OVER HEAD LINE CONFIGURATION DATA. [26]	40
TABLE 3.4 SHOWS THE SPACING ID CODING [26]	41
TABLE 3.5: LISTING THE LINE SEGMENT DATA. [26]	41
TABLE 3.6: UNDERGROUND CABLE CONFIGURATION [26].....	41
TABLE 3.7: TRANSFORMER DATA [26]	41
TABLE 3.8: CAPACITOR DATA. [26]	42
TABLE 3.9: LISTS THE POSITIVE, NEGATIVE & ZERO SEQUENCE IMPEDANCES SEEM FROM EACH BUS IN THE SYSTEM	44
TABLE 3.10: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 632	44
TABLE 3.11: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 633	45
TABLE 3.12: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 634.....	45
TABLE 3.13: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 671	46
TABLE 3.14: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 675	46
TABLE 3.15: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 680.....	47
TABLE 3.16: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 692.....	47
TABLE 3.17: SUMMARY OF FAULT CURRENTS FOR ALL TYPES OF FAULTS AT EACH FAULT LOCATION	48
TABLE 3.18: POSITIVE, NEGATIVE AND ZERO SEQUENCE IMPEDANCES AS SEEN FROM EACH BUS IN THE SYSTEM	49
TABLE 3.19: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 632	49
TABLE 3.20: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 633	50
TABLE 3.21: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 634	50

TABLE 3.22: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 671	51
TABLE 3.23: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 675	51
TABLE 3.24: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 680	52
TABLE 3.25: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 692	52
TABLE 3.26: SUMMARY OF FAULT CURRENTS FOR ALL TYPES OF FAULTS AT EACH FAULT LOCATION	53
TABLE 3.27: POSITIVE, NEGATIVE AND ZERO SEQUENCE IMPEDANCES AS SEEN FROM EACH BUS IN THE SYSTEM	53
TABLE 3.28: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 632	54
TABLE 3.29: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 633	54
TABLE 3.30: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 634	55
TABLE 3.31: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 671	55
TABLE 3.32: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 675	56
TABLE 3.33: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 680	56
TABLE 3.34: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 692	57
TABLE 3.35: SUMMARY OF FAULT CURRENTS FOR ALL TYPES OF FAULTS AT EACH FAULT LOCATION	57
TABLE 3.36: POSITIVE, NEGATIVE AND ZERO SEQUENCE IMPEDANCES AS SEEN FROM EACH BUS IN THE SYSTEM	58
TABLE 3.37: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 632	58
TABLE 3.38: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 633	59
TABLE 3.39: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 634	59
TABLE 3.40: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 671	60
TABLE 3.41: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 675	60

TABLE 3.42: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 680	61
TABLE 3.43: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 692	61
TABLE 3.44: SUMMARY OF FAULT CURRENTS FOR ALL TYPES OF FAULTS AT EACH FAULT LOCATION	62
TABLE 3.45: POSITIVE, NEGATIVE AND ZERO SEQUENCE IMPEDANCES AS SEEN FROM EACH BUS IN THE SYSTEM	62
TABLE 3.46: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 632	63
TABLE 3.47: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 633	63
TABLE 3.48: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 643	64
TABLE 3.49: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 671	64
TABLE 3.50: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 675	65
TABLE 3.51: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 680	65
TABLE 3.52: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 692	66
TABLE 3.53: SUMMARY OF FAULT CURRENTS FOR ALL TYPES OF FAULTS AT EACH FAULT LOCATION	66
TABLE 3.54: POSITIVE, NEGATIVE AND ZERO SEQUENCE IMPEDANCES AND SEEN FROM EACH BUS IN THE SYSTEM	67
TABLE 3.55: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 632	67
TABLE 3.56: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 633	68
TABLE 3.57: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 634	68
TABLE 3.58: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 671	69
TABLE 3.59: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 675	69
TABLE 3.60: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 680	70
TABLE 3.61: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 692	70

TABLE 3.62: SUMMARY OF FAULT CURRENTS FOR ALL TYPES OF FAULTS AT EACH FAULT LOCATION	71
TABLE 3.63: POSITIVE, NEGATIVE AND ZERO SEQUENCE IMPEDANCES AS SEEN FROM EACH BUS IN THE SYSTEM	73
TABLE 3.64: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 632	73
TABLE 3.65: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 633	74
TABLE 3.66: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 634	74
TABLE 3.67: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 671	75
TABLE 3.68: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 675	75
TABLE 3.69: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 680	76
TABLE 3.70: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 692	76
TABLE 3.71: SUMMARY OF FAULT CURRENTS FOR ALL TYPES OF FAULTS AT EACH FAULT LOCATION	77
TABLE 3.72: POSITIVE, NEGATIVE AND ZERO SEQUENCE IMPEDANCES AS SEEN FROM EACH BUS IN THE SYSTEM	79
TABLE 3.73: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 632	79
TABLE 3.74: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 633	80
TABLE 3.75: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 643	80
TABLE 3.76: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 671	81
TABLE 3.77: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 675	81
TABLE 3.78: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 680	82
TABLE 3.79: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 692	82
TABLE 3.80: SUMMARY OF FAULT CURRENTS FOR ALL TYPES OF FAULTS AT EACH FAULT LOCATION	83
TABLE 3.81: POSITIVE, NEGATIVE AND ZERO SEQUENCE IMPEDANCES AS SEEN FROM EACH BUS IN THE SYSTEM	83

TABLE 3.82: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 632	84
TABLE 3.83: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 633	84
TABLE 3.84: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 634	85
TABLE 3.85: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 671	85
TABLE 3.86: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 675	86
TABLE 3.87: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 680	86
TABLE 3.88: 3-PHASE & SINGLE LINE TO GROUND FAULT CURRENTS WHEN FAULT IS AT BUS 692	87
TABLE 3.89: SUMMARY OF FAULT CURRENTS FOR ALL TYPES OF FAULTS AT EACH FAULT LOCATION.....	87
TABLE 3.90: FAULT CURRENTS FOR ALL CASES WITH DIFFERENT FAULT LOCATIONS	88
TABLE 3.91: FAULT CURRENTS IN BRANCH FROM BUS 650 TO BUS 632.....	99
TABLE 3.92: FAULT CURRENTS FOR BRANCH FROM BUS 632 TO 671.....	102
TABLE A. 1. THE EFFECT OF THE DG'S MVA.....	118
TABLE A. 2 THE EFFECT OF THE DG'S LOCATION	118
TABLE A. 3: TIME DIAL AND PICKUP CURRENT SETTINGS WITH TWO DISTRIBUTED GENERATORS INTERCONNECTED	121

List of Symbols and Abbreviations

DG: Distributed Generation

PV: Photovoltaic

LTC: Load Tap changer

IGBT: insulated gate bipolar transistor

PCC: point of common coupling

ACSR : Aluminium Conductor Steel Reinforced

XFM-1 : Distribution Transformer number 1 in the IEEE test feeder

AA : Aluminium Conductor

Cu : Copper conductor

NDZ: non detective zone

I_p : Pickup Current

V_{rms} : Root Mean Square of the voltage

TDS: Time Dial Setting

T: Operating Time

T_{ijk} : operation time of relay i of branch j for fault k .

T_{nmk} : operation time of the first backup of R_{ij} for a given fault in protection zone k .

I_{ijk} : the current passing through the relay R_{ij} .

T_{CBB} : time of operation of circuit breaker B

T_{CBK} : time of operation of circuit breaker K

TDSA: time dial setting of relay A

TDSB : time dial setting of relay B

TDSC: time dial setting of relay C

TDSD: time dial setting of relay D

TDSE: time dial setting of relay E

TDSF: time dial setting of relay F

TDSG: time dial setting of relay G

TDSH: time dial setting of relay H

TDSI: time dial setting of relay I

TDSJ: time dial setting of relay J

TDSK: time dial setting of relay K

TDSL: time dial setting of relay L
TBA1: time of operation of relay A for a fault in zone 1 at its close end
TBB1: time of operation of relay B for a fault in zone 1 at its close end
TBC2: time of operation of relay C for a fault in zone 2 at its close end
TBE3: time of operation of relay E for a fault in zone 3 at its close end
TBD2: time of operation of relay D for a fault in zone 2 at its close end
TBK1: time of operation of relay K for a fault in zone 1 at its close end
TBF3: time of operation of relay F for a fault in zone 3 at its close end
TBG4: time of operation of relay G for a fault in zone 4 at its close end
TBH4: time of operation of relay H for a fault in zone 4 at its close end
TBI5: time of operation of relay I for a fault in zone 5 at its close end
TBJ5: time of operation of relay J for a fault in zone 5 at its close end
IpA: the pickup setting of relay A
IpB: the pickup setting of relay B
IpC: the pickup setting of relay C
IpE: the pickup setting of relay E
IpF: the pickup setting of relay F
IpG: the pickup setting of relay G
IpH: the pickup setting of relay H
IpI: the pickup setting of relay I
IpK: the pickup setting of relay K