

Intelligent Power Management: Improving Power Distribution in the Field

Michelle N. Gaffney
U.S. Army RDECOM CERDEC
Army Power Division
Fort Belvoir, VA

Summary

Power distribution systems are required in the tactical battlefield to enable safe and reliable distribution of power from the given generator set(s) to the Command Post (CP). The fielded US Army Power Distribution Illumination System, Electrical (PDISE) fulfills this basic need. In order to determine the effectiveness of the current power distribution scheme in the 500 W – 2 MW range, the Research, Development and Engineering Command (RDECOM) Communication and Electronics Research, Development and Engineering Center (CERDEC) Power Generation Branch in conjunction with the Project Manager for Mobile Electric Power (PM-MEP) and the Combined Arms Support Command (CASCOM) formed a field survey team. From this 2007 field survey it was found that soldiers do not have the knowledge base to set up a power grid, parallel generator sets or manually balance electrical loads. This leads to several issues including safety hazards, excessive power outages and brownouts, potential equipment failure, and inefficient utilization of power sources.

The Power Generation Branch, under the Intelligent Power Management (IPM) program, envisions implementing automatic load balancing and additional safety features in a new line of power distribution equipment to alleviate these issues in the field. Automatic load balancing is the ability for the power distribution system to automatically shift electrical loads from one phase of the generator set to another in order to enable a more balanced three phase electrical load. The safety features researched include monitoring the ground connection of the power grid, alerting the user to potentially unsafe connections and not allowing a line to energize until all cables are securely connected.

Currently the PM-MEP is looking to implement these features on a new line of power distribution systems for the US Army. Effort is underway to institute a program to build, test and evaluate systems that have these intelligent features incorporated.

Introduction

Currently the U.S. Army sets up power grids based upon recommended layouts from the PM-MEP. The power grid distribution and generation equipment is optimized for safety, initial cost, operational cost, transportability and readiness. In order to accomplish this optimization it is important for the correct size of generator set be chosen for a given Command Post (CP) configuration. In addition, if the electrical grid requires a 3-phase generator, equal amount of electrical load across each of the three phases of the generator set is required to balance the generator. A balanced generator set enables the most efficient utilization of power sources and maximizes the life of the generator set.

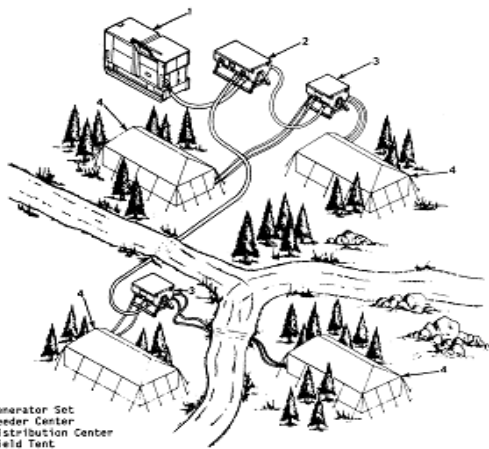


Figure 1: Power Grid Layout

A typical power grid setup consists of a power unit (one generator set) or a power plant (two generator sets, one for backup) connected to a network of power distribution systems that provide power to the electrical loads in individual shelters as seen in Figure 1. One physical connection of wire per generator set is ideal; any more than two physical connections of wires per generator set is against electrical safety code and may present a safety hazard. Currently the PM-MEP fields PDISE (Power Distribution and Illumination System, Electrical)

to enable the safe distribution of the power from the power units and power plants.

The PM-MEP has more than 10,000 pieces of PDISE equipment in the field with an overall requirement of 30,000 pieces. The PDISE line of equipment consists of six individual systems: the M200 feeder system, the M100 feeder system, the M60 distribution system, the M40 distribution system, the M46 duplex receptacles and the Universal Adapter. Figure 2 shows the main PDISE systems, M200, M100, M60 and M40.

An example of a typical CP setup is a Brigade Level Main CP. One 60kW power unit, one 30kW power unit and one 30kW power plant are utilized in a Brigade CP. To distribute the power from these generator sets, four M100 PDISE feeder systems are utilized with five M40 PDISE power distribution systems.



Figure 2: PDISE

Intelligent Power Management: Integrated Product Team

In the past several years, issues have surfaced regarding the integrity of the tactical power grid. Due to these surfacing issues the CERDEC formed an IPM IPT (Integrated Product Team) to determine what issues were widespread throughout the U.S. Armed Forces and to identify the root cause of these issues.

The IPM IPT included members from the CERDEC, the PM-MEP, the Power and Energy (P&E) Technology Integration Focus Team (TIFT) and the CASCOM. During the inaugural IPM IPT meeting the IPT decided it was necessary to form a field study team to investigate Warfighter needs first hand and to determine what issues were widespread throughout the U.S. Armed Forces.

Field surveys were conducted at Fort Bragg, NC, Fort Sam-Houston, TX, Fort Hood, TX, Fort Wainwright, AK, and an online survey distributed to all Power and Environmental Logistic Assistance Representatives (P&E LAR). Units including several Stryker Brigade Combat Teams (SBCT), Command Support Hospital (CSH), Brigade Support Battalions (BSB), and Signal Brigades were interviewed. In addition, the field survey team interviewed Infantry Divisions, Engineering Equipment Battalions, Airborne Units, Psychological Operations Units and representatives from the III Corp. Warfighters from the MOS 52D (Generator Mechanic) to general maintainer level as well as from the Senior Non-Commissioned Officer (NCO) to the operator level were interviewed who recently returned from deployment, including deployment to Iraq and Afghanistan.^{i,ii,iii}

IPM IPT Findings

From the field survey, the team found several common problems. The common problems and the field survey team's recommendations on solving these problems are listed below:

- ◆ Poor setup of the tactical power grid is the primary cause of all power issues in the field.
- ◆ Currently the procedure to properly balance electrical load across the phases of a generator set requires the shutdown of mission equipment.
- ◆ Proper grounding practices are rarely followed in the field.
- ◆ Uninterruptible Power Supplies (UPS) are insufficient to cover power outages

The primary cause of problems with power grids is that they are poorly setup. Warfighters do not have the knowledge base to set up a power grid, parallel generator sets or manually balance electrical loads. There is substantial Army guidance for setting up a tactical power grid in various manuals including FM 7-15^{iv}. In addition MOS 52D soldiers must pass Advanced Initial Training (AIT) which includes a Program of Instruction (POI) for thirty-nine (39) hours devoted to site selection, generator set installation, paralleling and power distribution. Despite these training opportunities the MOS 52Ds stated that their AIT did not adequately cover power distribution in general. Operators who set up the power grid layout for their units learn by trial and error. This leads to other power issues including unbalanced electrical loads, incorrect wiring of the generator set and improper use of power distribution equipment.

Even with a power grid that is initially setup by trained Warfighters there is a consistent issue with balancing phases in the field. Due to changing CP configurations, electrical loads are becoming imbalanced shortly after initial setup. Electrical load imbalance is causing premature tripping of circuit breakers and failure of mission essential equipment. Trained Warfighters must shutdown power to the tactical power grid in order to manually balance the electrical load across the three phases of the generator set. The issue of unbalanced electrical load is exacerbated when untrained soldiers setup the power grid. While the initial tactical power grid setup may

sustain operations, even slight changes to the load demand may cause enough of an imbalance to cause premature tripping of circuit breakers or a failure of mission essential equipment. In addition, unbalanced loads may lead to severe underutilization of power units and power plants.

Proper grounding practices are not followed in the field. The majority of the units interviewed designated that lack of a proper ground was the number one safety issue with power generation and distribution equipment. Currently no major injuries or deaths have been reported however the lack of ground is a serious safety issue.

Uninterruptible Power Supplies (UPS) are insufficient to cover power outages. All units interviewed had a requirement for uninterrupted twenty-four (24) hour operations. All units employed UPS systems to ensure this operation however the majority of units stated that their UPS were not able to sustain operation between generator set shut down and the restart of generator set operation. The field study team believes this is not an issue of inadequate UPS systems but an issue with excessive time to regain generator set operation. The field study team believes this is a lack of training, specifically on diagnosing the cause for generator set shutdown.

IPM IPT Recommendations

The field study team recommended the use of several IPM features to alleviate the issues raised. These features include automatic load balancing and system electrical safety features as a threshold requirement. Automatic load balancing is the ability for the distribution system to actively balance the electrical load between the three phases of the generator set. The system electrical safety features recommended were Protective Conductor Loop Monitoring (PCLM) and ground monitoring features. These IPM features should reduce the training burden on the soldiers. The field study team also recommended the use of software tools such as AutoDISE to assist with power grid setup. The field survey team recommended the use of automated diagnostics and prognostics of generator set failure as an objective requirement. Automated diagnostics are methods used to identify the cause of a particular generator set failure. Prognostics are methods used to analyze past trends to allow for predication of future failures. This would assist the Warfighter with diagnosing current and alerting them to potential future problems with the generator set.^v

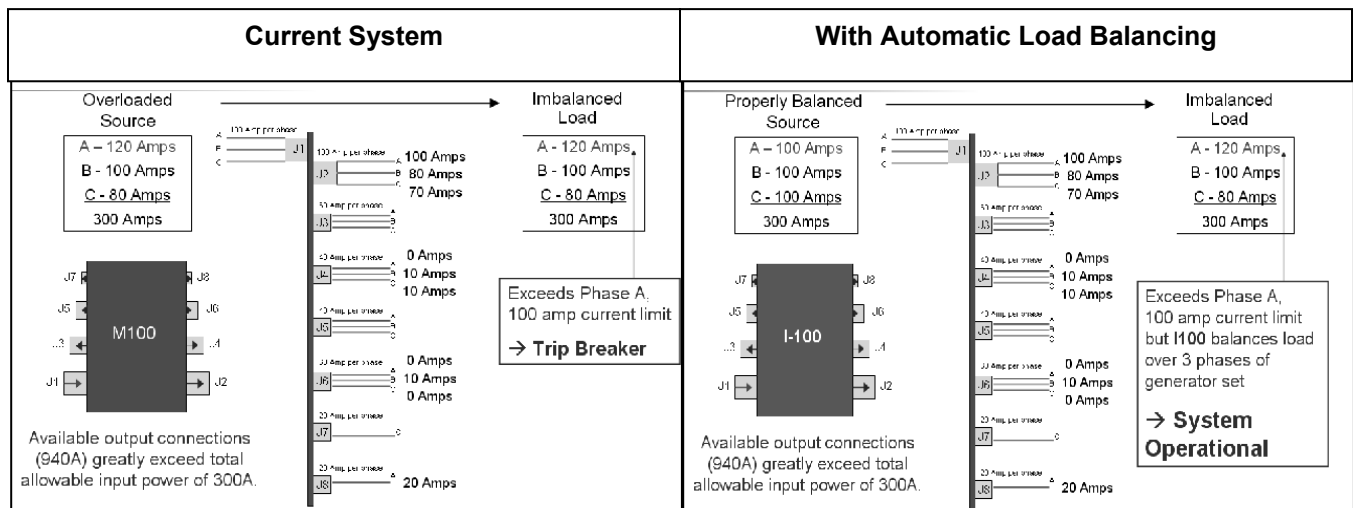


Figure 3: Automatic Load Balancing

Automatic load balancing would address the issues seen with time lost due to establishing a proper power grid setup, problems encountered due to poor power grid setup and improper electrical load balance. Electrical load imbalance causes premature tripping of circuit breakers, underutilization of power units and power plants and failure of mission essential equipment. Figure 3 above shows a pictorial representation of the concept of automatic load balancing. The electrical safety features would address all safety issues. The PCLM feature would monitor the proper connection of cables to one another while the ground monitoring features would monitor the proper connection of ground.

IPM System Development & Test

The CERDEC brought in several systems from industry to test the various features recommended by the IPM IPT. An initial prototype unit featuring automatic load balancing was taken to the C4ISR OTM (Command, Control, Computers, Communications, Intelligence, Surveillance and Reconnaissance On The Move) demonstration in 2007. Potential issues were identified and additional research and development was conducted to correct these issues. The upgraded system was then taken to TOCFEST in April 2008.

PEO C3T initiated the first Operation TOCFEST "to develop a recognized standard that is supported by a completely engineered, interoperable, integrated system-of-systems tactical command post, or command posts, to the Warfighter."^{VI} Operation TOCFEST was an engineering exercise focused on the overall proper setup, use and operation of CPs, formerly known as Tactical Operations Centers (TOC). Operation TOCFEST employed one brigade level main CP, a battalion level CP and a battalion level Tactical Command Post (TAC).

The prototype unit was taken to TOCFEST and inserted into the existing scenario replacing the M100 PDISE box powering the C4 Operations tent. This M100 PDISE box fed three, three-phase outputs: one M40 PDISE box for the Plans tent, one Joint Network Node (JNN-2) shelter and one Command Post Platform (CPP-B) shelter. The M100 box also powered four, single-phase electrical loads: three 20 amp single-phase lines and one M60 PDISE box, all powering the C4 Operations shelter.

A diagram of the setup after the technology insertion of the prototype unit as seen at TOCFEST from 03 April 2008 – 08 April 2008 may be viewed in Figure 4.

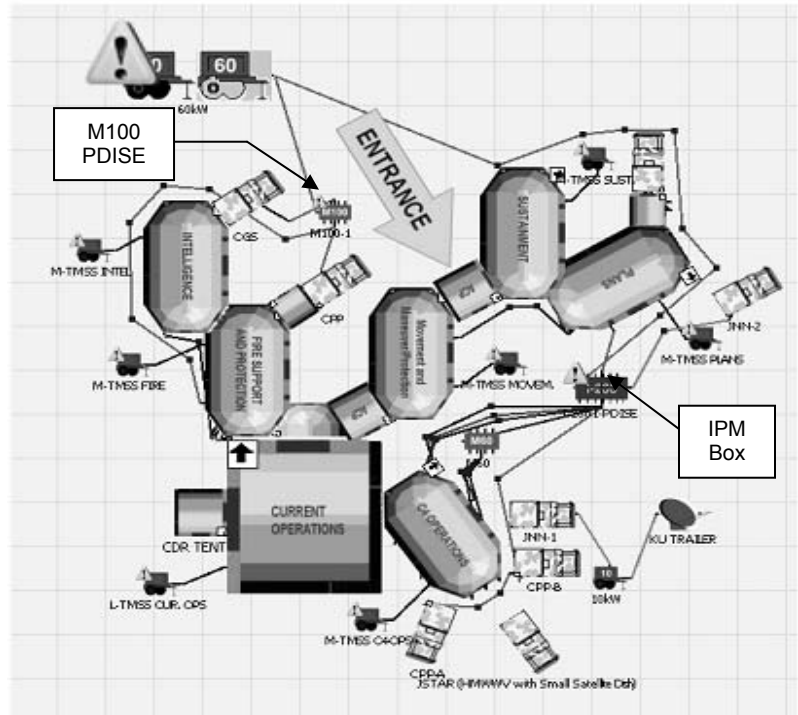


Figure 4: TOCFEST Layout

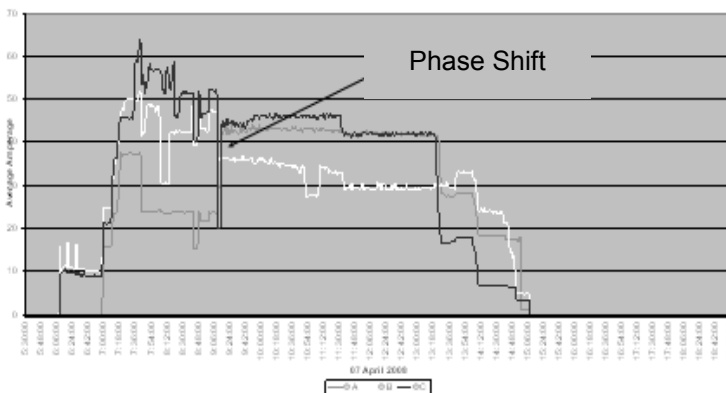


Figure 5: Phase Shift

The system was run with the given electrical loads of each day. The prototype system initiated a phase shift each day to enable a better balanced system. An example of this phase shift is seen in Figure 5. Figure 5 shows the total input electrical load throughout the day Monday, 07 April 2008. Phase C is the highly loaded phase, this is predominately from a large single phase electrical load initially located on Phase C. In addition, Phase B has a large electrical load with Phase A being very under-loaded compared to the other two phases. The prototype unit shifted the large single phase electrical load from Phase C to Phase A, and the two smaller single phase electrical loads from Phase A and Phase B to Phase C. This can be seen in Figure 5 by the dramatic increase in electrical load of Phase A. Phase C electrical loads did not drop significantly since the smaller single phase electrical loads were shifted to Phase C to make up for the large shift of to Phase A.

The imbalance of the phases was calculated for each phase and for the total overall imbalance of the system. The per phase percent imbalance was calculated utilizing the following equations:

$$\left| \phi A - \left(\frac{\phi A + \phi B + \phi C}{3} \right) \right| = \phi A_{Imbalance}$$

Equation 1: ΦA Imbalance

$$\left| \phi B - \left(\frac{\phi A + \phi B + \phi C}{3} \right) \right| = \phi B_{Imbalance}$$

Equation 2: ΦB Imbalance

$$\left| \phi C - \left(\frac{\phi A + \phi B + \phi C}{3} \right) \right| = \phi C_{Imbalance}$$

Equation 3: ΦC Imbalance

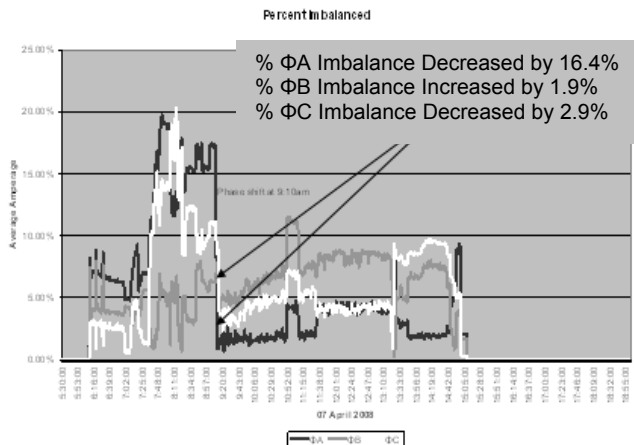


Figure 6: Percent Imbalance per Phase

Figure 6 shows the percent imbalance of each phase throughout the day. The shift in phases can be seen by the slight increase in imbalance of ΦB , the slight decrease in imbalance of ΦC and the large decrease in imbalance of ΦA . With the shifting of the large single phase electrical load from ΦC to ΦA the imbalance of ΦA drastically decreased from 17.24% imbalanced to 0.88% imbalance. This is a 16.4% decrease in imbalance.

In addition to calculating the total percent imbalance per phase, a total percent imbalance was calculated based upon the total rating of the system. This percent imbalance calculation is used for all RDECOM CERDEC Power Generation Branch system assessments. For this case, the total rating of the system is stated to be 100 amps. The prototype unit utilized at TOCFEST was a 100 amp power distribution system that replaced the current 100 amp PDISE system, the M100. The total percent imbalance was calculated utilizing the following equation:

$$Assessment_{Imbalance} = \left(\frac{MAX(\phi A, \phi B, \phi C) - MIN(\phi A, \phi B, \phi C)}{100} \right)$$

Equation 4: Percent Imbalance

The average imbalance of the system before the phase shift occurred is approximately 28.2%. As Figure 7 shows, the total percent imbalance decreases by 11.9% after the phase shift from 28.2% to 16.2%. The prototype unit successfully shifted the single phase electrical loads of all three phases for an overall decrease in the percent imbalance of the generator of 11.9% when calculated based on rating.^{vii}

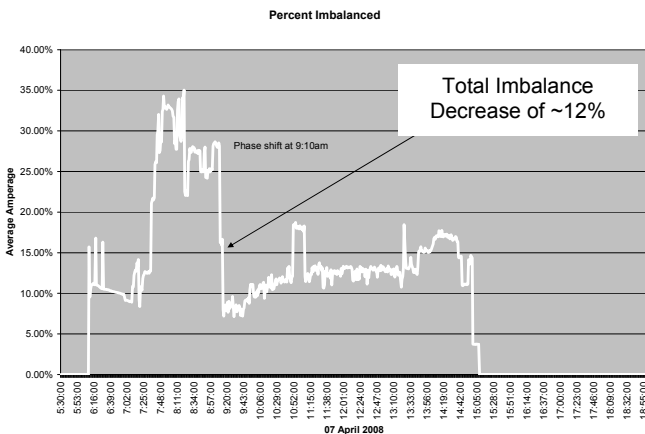


Figure 7: Total Percent Imbalance

The prototype unit was successfully demonstrated at Operation TOCFEST. The prototype unit successfully balanced the electrical load under various three-phase electrical load scenarios. With a 28% imbalanced system, the prototype unit demonstrated an improved balance of almost 12% when calculated based on rating. No issues or failures occurred at any point during operations at TOCFEST. Minor recommendations and issues were seen after conclusion of Operation TOCFEST and these issues are currently being addressed by CERDEC and PM MEP. In addition, Operation TOCFEST represented the best case scenario for a balanced CP layout since it was an engineering exercise conducted by U.S. Army recognized experts on power grid setup.

Although the power grid was setup per U.S. Army standards to ensure balance across the three phases of the generator set, the prototype unit still enabled automatic phase balancing to improve the balance of the setup by

an additional 2% when calculated based on rating. Overall, the technology insertion of the prototype unit was a success at Operation TOCFEST.

Integration of IPM into the Power Grid

The PM-MEP and the CERDEC are enabling the integration of IPM into the power grid in two ways. First, the CERDEC is leading a Defense Acquisition Challenge (DAC) program to develop a 100 amp Intelligent Power Management and Distribution System (IPMDS) that enables the above recommended features of automatic load balancing and electrical safety features. The DAC program will allow for the test & evaluation with the potential for follow-on procurement of a 100 amp IPMDS system. In addition, the CERDEC is currently drafting a performance specification for a new line of power distribution systems for the U.S. Army. This performance specification will be based upon the requirements of the Tactical Electric Power (TEP) Capabilities Production Document (CPD) which is currently in draft format. The TEP CPD includes objective requirements for intelligence inside the power distribution family. This performance specification will allow for a procurement cycle for a new line of intelligent power distribution systems.

Conclusion

The integration of IPM into power distribution systems will have numerous benefits to the U.S. Army and other services. IPM will allow for reduced time to setup and establish an effective and efficient power grid. IPM will allow for increased availability of usable power at the duplex receptacle through proper balance of electrical load across the three phases on the generator set. Both of these benefits will lead to maintaining a high level of mission readiness. The integration of IPM into power distribution systems may allow for decreased fuel consumption through more effective and efficient utilization of existing power units and power plants. This will allow for decreased number of required fuel convoys and increased mission readiness. In addition, IPM will have safety features that protect our Warfighters from dangerous and potentially life threatening situations. Overall IPM will reduce the training burden on the Warfighter, increase reliability of the power grid, decrease critical mission equipment failures, increase the safety of the power grid and create a more efficient use of power units.

ⁱ Gaffney, Michelle, "Intelligent Power Management Interim Report: Fort Bragg Field Survey," APPG-TR-06-09, Oct. 2006.

ⁱⁱ Gaffney, Michelle, "Intelligent Power Management Interim Report: Fort Sam Houston and Fort Hood Field Surveys," APPG-TR-06-10, Dec. 2006.

ⁱⁱⁱ Gaffney, Michelle, "Intelligent Power Management Interim Report: Fort Wainwright Field Survey," APPG-TR-07-06, Jun. 2007.

^{iv} Department of the Army, Headquarters, The Army Universal Task List, pp. 6.10.4, Washington, DC, 2003.

^v Gaffney, Michelle, et al., "IPM Final Report," APPG-TR-07-07, Jul. 2007.

^{vi} "Engineers Meet to Improve Digital TOCs." Defense Department Document and Publication/Content Works via Comtex. 26 March 2008. 09 June 2008 <<http://connorsresearch.net/site/news/Stock%20News/1255512/?hcode=relatednews>>.

^{vii} M.N. Gaffney, "I-200 Technology Insertion Report (TOCFEST)," APPG-TR-08-03, Jun. 2008.