Investigating the Effect of Electromagnetic Protection on the Reliability and Maintenance Expenses of Tier 1 and 2 Data Centers

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Abstract - Information is growing at an increasing speed in this developing world of technology.Therefore, for all organizations, collectinginformationand creating integrated storage systemsare vital,so that the data centers in massive collections has turned intothe necessity. Many data centers are of great importance, in which sustainability, service speed, business continuity and survival of organizations are created via their efficient functionality. Due to the vulnerability of data centers to electromagnetic threats, it is inevitably necessary to find ways to protect them against these threats.Implementation of electromagnetic protection measures in these centers is the method to cope with this problem. But, senior executives may be doubtful about implementing this method due to the high cost of applying electromagnetic protection of a data center with regard to the cost-benefit principle. Therefore, in the presentstudy, we proposed a probabilistic method with Monte Carlo simulation to investigate the effects of data centers' protectionagainst electromagnetic threatson the power infrastructure, reliability, precision, and cost of serviceoutage.

Keywords: Monte Carlo Simulation, Reliability, Electromagnetic Protection, Power Infrastructure, Data Centers, Cost of Outage

1. Introduction

1.1. Research Aim

Information is being produced and grown at an increasing speed keeping pace with the high speed of developing technology. Therefore, protecting information and creating integrated storage systems is vital for all organizations, and the creation of data centers recording massive collections has become a requirement.The data center is briefly referred to a set of elements, such as the physical environment, servers, data storage environments, communications, and services creating sustainability, service speed , business continuity and survival of the organizations by their effective functioning.

In Iran, there are many data centers which are critical and vital for sustaining many activities[1]. Therefore, it is essential to ensure continuity of service during both wartime and peacetime.Regarding the principle of the continuity of activities during the wartime, and the vulnerability of data centers to electromagnetic threats, data protection is inevitably imperative.

In order to deal with the electromagnetic threats, electromagnetic protection measures should be implemented at these centers, which are naturally costly. Considering the cost-benefitprinciple in nonpermanent defense, senior executives may not be surely willing to implement them.

In this paper, we have investigatedthe changes which may occur in the service failure or service outage if a data center is protected against electromagnetic attacks, along with the expenses of a data center such as repair, maintenance, service outage, to help with the decision-making process of senior executives on the electromagnetic protection of data centers by using simulation of the block diagram of the reliability of the powerinfrastructure of a data center in the context of MATLAB software via probabilistic method.

1.2. Articles Review

In the late 1990s and early 2000s, the IT services made a quick progress and became known as a convenient means of providing services, and computer networks and data centers made a boom in generating income and expansion of commerce, and since then, the economic blows from the data centers have also increased at an unprecedented rate.

Even though, most of the financial enterprises are more dependent on their data centers to support important businesses, major vulnerabilities in data center powerinfrastructure and wrong impression of the IT equipment recurrence period and its high cost would increase the loss risk of anoutage[2]. This issue has led to new studies on the reliability of these centers, which directly affectsthe continuity of their service.

Initial Definition of Reliability:

In any construction project, reliability is one of the key points for strong designing. Nowadays, the reliability assessment is of increasing importance both in mass production and systems with high sensitivity. One of these systems is data centers that need to work on a permanent basis under different conditions.Therefore, the reliability of designing data centers is a very important parameter. In order to maintain proper operation and service of these centers, reliability and maintainability assessment methods should be implemented at all phases of development. By definition, reliability is the probability that the product can maintain the desired performance under specified conditions over a certain time. Therefore, the numerical reliability value is between 0 and 1, where the state of the number 1 represents the ideal state, in which the proper operation of the product is never disturbed [3].

The levels of reliability and economics are mutually dependent, in a way that for increasingthe reliability, the investment must be increased, and also reliability reduces the cost of service outage for customers [4]. Indicators like availability, Mean Time Between Failure (MTBF), and Mean TimeToRepair (MTTR) are used in the Measurement of reliability. And also, a reliable source of data of the system's components is useful for detailed and concise analysis.

In this paper, reliability data has been derived from the IEEE 493 GoldBook standard.In order to obtain the reliability of a data center, first block of reliability diagram has been drawn up, then, using the Monte Carlo simulation, the final result has been obtained in the MATLAB software [5].

Definitions:

Availability: that’s a specific relation whichrepresents the percentage of time that a particular element or system can perform the required function.

Lambda (λ): that is the reverse average of time between two successive failures which is usually expressed as a yearly failure or a failure in a million hours.

MTBF (mean time between failures): That indicates themean time between two successive failures of an element or system which is usually expressed as a yearly failure or a million hours offailure.For some applications, measurements with the mean time between changes (MTBRs) may provide more accurateor correct statistics.

MTTR (mean time to restart): That indicates themean time required repairing an element. For a system, this index is equal to the total time that is not available due to failure, and is expressed in terms of clock [5].

Reliability Assessment Methods:

Accurate and correct calculation of probability measures of reliability greatly influences the process of planning for the development of a power center of data centers. For this reason, various tools and methods for obtaining these criteria in the power system were introduced.The proposed methods were divided into two general tiers of analytical methods and simulation methods.Each of these two tiers has its own pros and cons and no one can be superior over the other. Markov modeling is an analytical method, but in the simulation process, the Monte Carlo method is very useful [6].

Assessment of the Data CentersPower System Reliability by the Monte Carlo Method:

Monte Carlo simulations are commonly spoken in broad terms, and in fact are being equally used in many studies in various systems. This tool is for modeling processes that have completely random aspects, and the complexity of the system does not allow for further development and composition of mathematical equations in a simple and logical way. In this situation, examination of the obtained results of system performance requires simulating the conditions under which the system operates.

Indeed, Monte Carlo is used to simulate states of the system in a completely random manner. This series of experiments is based on random numbers that are simulated by processes which are being performed by computers today, and the final results are being obtained for analyzing the behavior of the system [6].

As stated before, systems under simulation are not explainable mathematicallydue to complexity, and simple logical relations cannot be presented to express the behavior of the system.Using Monte Carlo simulations on the system, theobtained resultsdescribe the behavior of the system in dealing with completely random conditions.Indeed, in the Monte Carlo simulation what matters is analysis and examination of results.

An important point to mention here is the existence and validity of intra-system relationships such as electric power-flow. Indeed, the system has multiple segments that have distinctive relationships, and these relations are expressed mathematically. Interactionof this part of the system requires conditions in whichequations are complicated. In this case, the results out of Monte Carlo are used to evaluate the system's overall performance [7].

Monte Carlo Foundations:

Repetition of a random behavior in an uncertain system is the main function of Monte Carlo. In the simulation of power systems, the Monte Carlo output typically includes the number of the repetitions of certain values or the distribution function of a particular parameter.One of the problems in the Monte Carlo simulation process is the generation of random numbers for creating random conditions.Today, with the help of digital computers, this problem has become a simple part of anissue. In these computers, numbers are generated in the intervals between zero and one in a randomized and normalized way. Primary distribution in these numbers is a uniform distribution, but can be converted into special distribution functions such as normal ones.

The number of repetitions of the simulation operations must be followed up, so that the results converge to the real value. This approximation to the final value can have different criteria, and depending on the accuracy of the problem in determining the final answer, the number of repetitions can vary. Depending on the type of Monte Carlo algorithm application, several indicators are available for the final stop. Usually, the selection of the index is done in such a way that the worst possible condition was beingobserved. In this case, with the approach to an index in simulating other indicators, they also obtain their own allowed values [6].

Tiering Data Center Based on Reliability Level

Tiering levels of the infrastructures of a data center should be considered in order to design facilities for them. In the TIA-992 Standard (Appendix G) TIA, has been considered as a leading cooperation in the field of global information and communication technology. This forum is approved by ANSI.) Data centers are tiered as one to four in terms of the infrastructure required by a site to obtain different levels of reliability. Here is the specification of data centers intiers 1 and 2 [8]:

Tier1:

That does not include the adjunctive component and its specifications include the following: (Figure 1)

- Reliability is% 99.671
- Susceptible to outage due to planned or unwanted activities.
- It must be completely turned off to conduct the preventive maintenance operations.
- The annual outage is 28.8 hours.
- It has a direction for recharging and cooling.

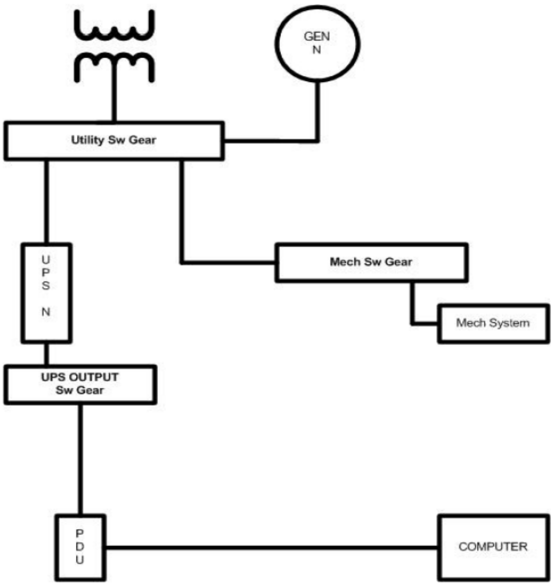


Figure (1): Block Diagram for Power Infrastructure of Data Center Tier 1.

Tier2:

That contains the adjunctive elements and has the following characteristics (Figure 2)

- Its reliability is 99.741%
- It is Less Susceptible to outage due to planned or unplanned activities.
- It has a route for recharging and cooling, but includes adjunctive elements (1+ N).
- Includes false floor (up raised), ups and diesel generator.
- Its annual outage is 22 hours.

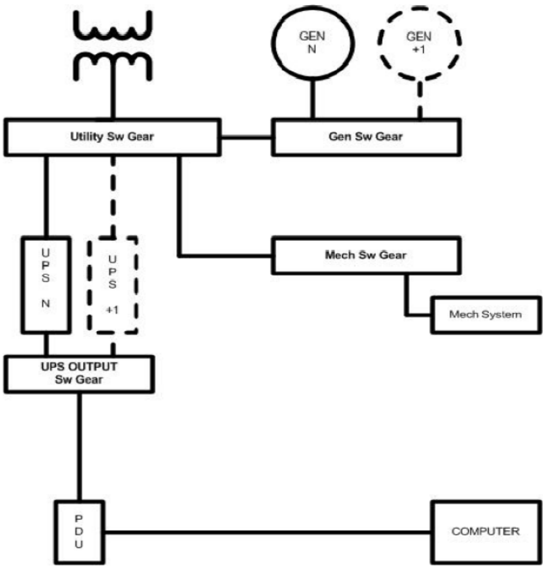


Figure (2) Block Diagram of Data Center Power Infrastructure

Several studies whichhave investigated the reliability of the data center infrastructure using different approaches and methods have been introduced.

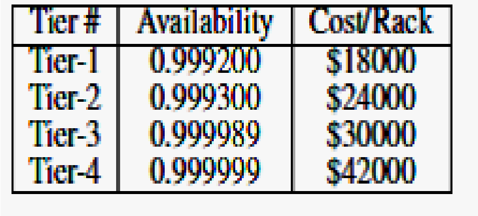
In study [5], the failure of data centers has been empirically studied. In this study, after the initial definitions of reliability, the power structure and the reliability block diagram of a tier 4 data center by simulating the RBD have been investigated At first, the reliability block diagram was drawn up in order to obtain the reliability of a data center of tier 4. Then the reliability information for each element from the IEEE Gold Book 493 source was derived.

In the following study, FMECA method which is used for analyzing and evaluating a system failure, and based on obtaining reliability by simulation with Block Sim7 software, is provided.

In order to improve the reliability of the data center, a diesel generator and a number of other elements were added through a particular topology to the data center power infrastructure of tier 4, which entails a great deal of cost.

In study [9], with the aim of realization of a data center with high reliability and low cost, has addressed the issue by regarding the costs which should be incurred if the reliability of a data center changes from one tier to a higher one.In Table 1, the cost of building data center infrastructure in different tiers is mentioned based on the number of server racks.

Table (1) The Cost of Building Data Center Infrastructure in Different tiers, with the Number of Server Racks



Tier #	Availability	Cost/Rack
Tier-1	0.999200	$18000
Tier-2	0.999300	$24000
Tier-3	0.999989	$30000
Tier-4	0.999999	$42000

In the following parts, with the Markov chain of continuity data centers power infrastructure reliability,the cost of adding UPS with different capacities and PDUs has been estimated in different levels. In this reference, different combinations of UPS and PDU placement are proposed to increase the reliability of data centers.

In study[10], with the aim of the comparing different types of UPS placement in data centers, at first, the cost of building data center structures with different tiers has been shown in a tableand, consequently, various reliabilities have been examined, and then, various types of powerinfrastructural structures of these centers, based on the location and number of UPSs, have been described and the advantages and disadvantages of each of them were named. At the end, we have providedguidance on choosing the appropriate power infrastructure structures in different circumstances.

In the study [11], which is valid forcalculating the reliability of various power infrastructures, the bases of reliability analysis for planning and designing power distribution systems for industrial and commercial centers were presented including the concepts of reliability analysis via probabilisticmethod, bases for assessing the reliability of power systems, economic reliability assessment, calculation of poweroutage costs, data on the reliability of power infrastructure equipment, initiating and participating factors in equipment failure and the elements and consequences of their failure, as well as examples of reliability analysis.

1.3. Method and Innovation

The power infrastructure of the data centers and its related parameters, like the reliability and cost of creating, repairing, maintaining, and outage of their services, and each proposed different ways to optimize power infrastructure and reduce costs, have been examined by several studies. All of these suggestions have the following in common:

1- Increasing the elements of the power infrastructure
2- Optimization of the insertion of adjunctive elements
3- Reducing or eliminating the root causes of the failure of the elements

Each study has provided solutions in order to reduce or eliminate the root causes of the failure of the elements according to the orientation of the researchers along with existing tools; but, in particular, the effects of electromagnetic protection on the failure rate of the elements, the reliability of the data centerpower infrastructure as well as the cost of service outage have not been investigated. In this paper, these effectshave been calculated via simulation on the Reliability Block Diagram (RBD) of the data center infrastructures of the tiers 1 and 2, by MATLAB and the changes in the amount of service outage cost of these centers, after and before the electromagnetism protection have been compared; the stages of which are as follows:

The power infrastructure of data centers in the tiers 1 and 2, is the first stage of RBD drawing. Considering the specific standards and definitions, the way the elements of the power infrastructure of data centers are located based on their impacts on its reliability is examined.

In the second stage, first, the parameters of reliability of the constituent components of the power infrastructure are derived regarding different standards, then, a table that matches the RBD of each tier of data center, is drawn using this information. By entering this table in the MATLAB Simulator, the reliability of the data centers power infrastructure is calculated in tiers 1 and 2.

In the third step, the effects of electromagnetic protection on the parameters determining the reliability of the elements by statistical method were investigated. The information table of the RBD, and subsequently, the values computed by the simulator program changed by changing these parameters.The exact amount of service outage as well as the resulting annual cost would vary by changing the reliability of data centers. These differences were alsocalculated in annual data center costs.

2. Statement of Problem

The power infrastructure of a data center first must be modeled in order to calculate its reliability,which has been discussed in this section.

1.2. Reliability Data Center Model

Reliability analysis becomes difficult when industrial and commercial power systems are complicated and repairable. There are normally two steps to obtain system reliability indicators:

1) Make a reliability system model
2) Analyze the model

The system's reliability model harmonizes the structure of the system and its behavior.Of course, it depends on how well the structure of the system and its behavior are comprehended and what assumptions, tools, and methods of modeling are considered in it.

The RBD method has been used as a functional reliability modeling technique for commercial and industrial power systems [12].

A logical connection between components and sub-system levels was illustrated by a reliability block diagram (RBD). This method is a graphical demonstration of a system diagram in terms of reliability or logic: for example, the connection of subsystems or components according to their performance or their reliability relationship is searched in this method.

The reliability diagram shows which combination of component failure causes system failure, or, which combination of components works correctly, and keeps the system active.Therefore, RBDs are based on the system design, maintenance methods, performance, and analysis of component failure effects. Observing a block in the RBD shows that a physical component works well, and the removal of the associated blockis the indication of the failure of that component.

The connection between the input and output points gets disconnected when enough blocks are removed in an RBD system.In other words, if there was only one communication path between the input and output, the system would still work correctly [13].

The power infrastructure of a data center includes generators; uninterrupted power supplies UPS batteries, transmission switches, transformers, circuit breakers, power distribution units or PDUs and power output units or POUs.

Figure 3 represents an example of the architecture of the power system of a data center including sub-systems and their constituent systems [14].

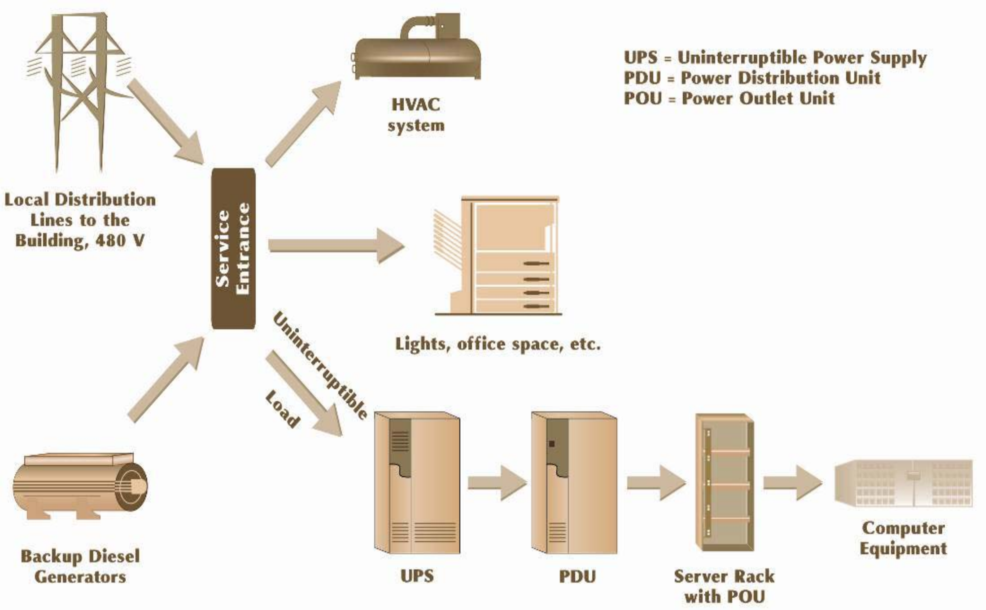


Figure 3- An Example of the Data CenterPowerSystem Architecture

A single-line diagram of an associated network with a data center of degree is indicated in Figure 4 1. Of course, in these shapes, only the power route is brought to the server rack. As you can see in this block diagram, this data center has two power supplies, including the public distribution system and diesel generator, which are connected to the server rack through a UPS. When the power is not transfered to the load points within a few milliseconds, the system may get disconnected.

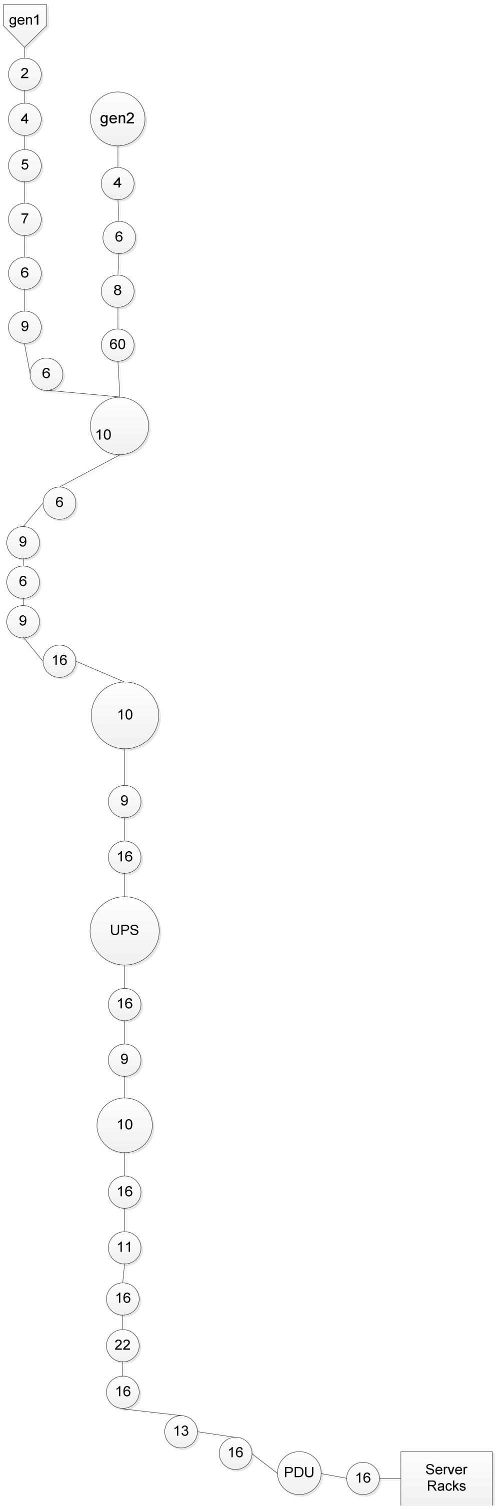


Figure 4- A Single-Line Diagram of anAssociated Network with a Data Center of Degree 1 [15].

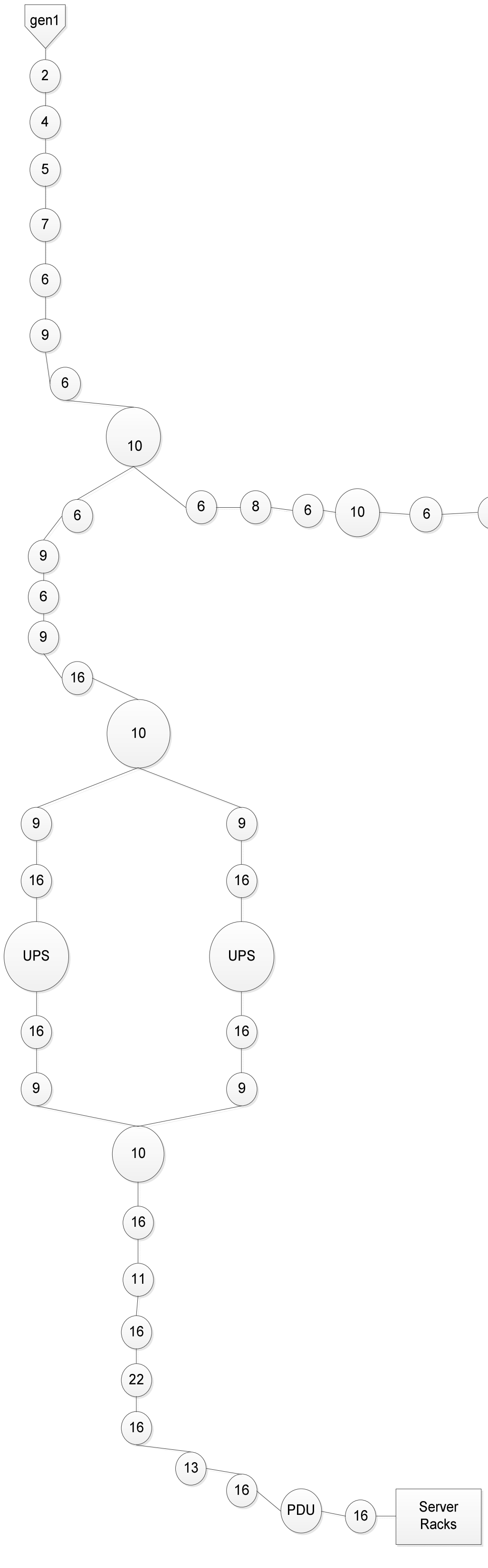


Figure 5- A Single-Line Diagram of anAssociated Network with a Data Center of Degree 2 [15].

A single-line diagram of an associated network with a data center of degree 2 is indicated in figure 5. As can be seen in this figure, a diesel generator is added to the data centerpower route and besides, another UPS is conjugated with other sources, which is redundant.

It is obvious that the reliability of data centers is increased by increasingpower sources. And increasing power sources subsequently entails costs that needs to be considered in terms of the cost-benefit principle of a data center.

The numbers in the above figures, each of which relating to a component in Table 2, identify the components inside the network. All equipment reliability data are derived from the 2007 IEEE 493 Gold Book, Edition of 2007.

Table 2- Specifications of the Constructed Elements of the Data CenterPower Infrastructure [11]

REF #	ITEM DESCRIPTION	MTTR(h)	Failure rate (λ) failure/year
1	Single Circuit Utility Supply, 1,78 failures/unit, A=0.999705, Gold Book p.107	0.99971	1.956
2	Cable aerial, ≤ 15kV, per mile	1.82	0.04717
3	Diesel engine generator,packaged, , 1500 kW	25.74	0.58269
4	Manual disconnect switch	1	0.00174
5	Fuse, 15 kV	4	0.10154
6	Cable belowground in conduit,≤ 600 V, per 1000 ft	11.22	0.00201
7	Transformer, liquid, nonforced air, 3000 kVA	5	0.00111
8	Circuit breaker, 600 V, drawout, normally open,> 600 A	2	0.00553
9	Circuit breaker, 600 V,drawout, normally closed,> 600 A	0.5	0.000925
10	Switchgear, bare bus, 600 V	7.29	0.00949
11	Circuit breaker, 600 V drawout, normally closed, < 600 A	6	0.00021
12	Circuit breaker, 600 V,normally closed, > 600 A	9.6	0.0096
13	Circuit breaker, 3-phasefixed, normally closed,≤ 600 A	5.8	0.0052
16	Cable, aboveground, trays,≤ 600 V, per 1000 ft	10.5	0.00141
22	Switchgear, insulated bus,≤ 600 V	2.4	0.0017
60	Cable, above ground,No Conduit, ≤ 600 V, per 1000 ft	2.5	0.000096
ups	UPS, rotary	6	0.00402
Pdu	Transformer, dry, air cooled , <=500 kVA + Circuit breaker	10	7.36088E-06

In a normal mode, a public source provides power through an automatic transmission switch (ATS), and a UPS is coupled in same direction ofpowerwith the load points from a common source. But, when the public electricity is cut off, power is supplied by the UPS (which has a rechargeable battery). After 10 to 20 seconds delay, Gen-set is ready, and the automatic transfer switch after this time allows the Gen-set to add its stable output to the circuit. Gen-set also provides power supply for UPS charging. There is a resistance time which depends on the capacity of the Gen-set and the UPS at the load points. UPS and Gen-set are returned to the normal mode by an automatic transfer switch as soon as the public electricity returns to normal [5].

2.2. A Proposed Method for Assessing the Reliability of Data Centers

In order to find the reliable models, variousanalysis methods have been used. When it is not feasible to calculate precisely, RBD-based simulation methods can be a good solution to achieve the reliability of complex systems.

Simulation techniques are powerful tools that enable engineers and managers to study the behavior and function of systems and learn about external factors that influence the reliability of the system. Accurate solutions for calculating system reliability are provided by simulation. The concept of simulation is simple: It is just a series of numerical tests on the RBD.

In this study, the MonteCarlo simulation has been used on the reliability block diagram in the MATLAB software environment to calibrate the reliability of a data center.

The real modes of each block are simulated.Related events (work or failure) are recorded as they happen at times when random processes which are the distribution function of the failure rate or block repair, are determined during the movement and examination of a block.

Testing on a block’s modes is done over time to collect the history of the system (failure-health), after simulating the operation. All reliability indicators are easily obtained with satisfactory accuracy when a large number of tests are performed on system records. Theoretically, the precise and correct value will be produced by the infinite number of experiments.

2.3. Steps of Simulation

First, the data center reliability block diagram was drawn, and then the blocks were numbered based on the order. It is noteworthy to consider that this kind of numbering is different from the determinant numbers of the element forming type of each block, as presented in the 2007 edition of IEEE 493 Gold Book Standard. Nodes which are actually blocks connecting pointswere also numbered.In Figure 6, an example of the block numbering is indicated in the data center reliability block diagram tier 1.

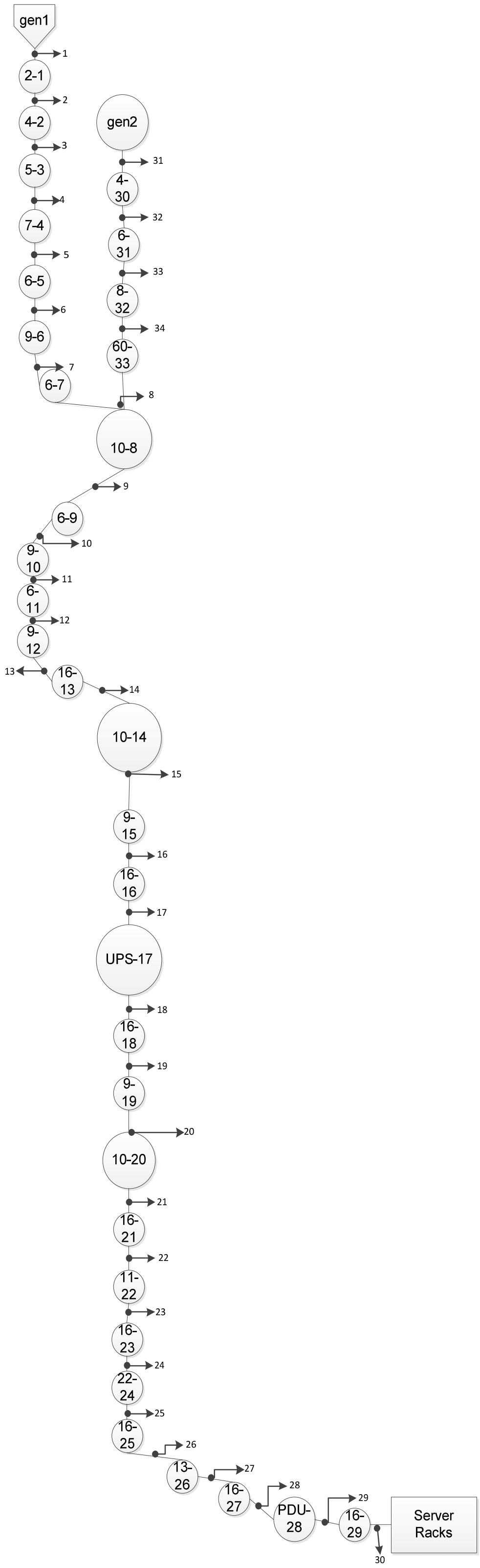


Figure 6- The Numbering of Blocks and Nodes of a Single-Line Diagram of anAssociated Network with a Data Center of Degree 1

In the next step, in the table below the followings will be included:

- The number of each block
- The previous node number of each block (From Node).
- The next node number of each block (To Node). (The number before and after each block indicates that what elements, each block or element is associated with.)
- Failure rate for each block (λ).
- Mean time to repair each block (MTTR).
- The probability of failure of each block (Failure Probability).

In order to obtain the probability of failure of a block or element, the following steps are followed:

First, the number 8760, which is the number of hours a year, is divided by MTTR (μ).

1- $$\mu = \left(\frac{8760}{MTTR} \right)$$

Then, in order to obtain the probability of failure, (λ) is divided by (μ+λ):

2- $$failure\ probabilit\,y = \left(\frac{\lambda}{\lambda + \mu} \right)$$

All information in Table 3 should be copied to the simulator software in a file called RBD, which is a sub-program.

Table 3- The Initial table for Importing into the MATLAB Simulator Software

component	from node	to node	MTTR	Failure rate(λ)	Failure probability
1	1	2	1.82	0.04717	9.80006E-06
2	2	3	1	0.00174	1.9863E-07
3	3	4	4	0.10154	4.63631E-05
4	4	5	5	0.00111	6.33561E-07
5	5	6	11.22	0.00201	2.57445E-06
6	6	7	0.5	0.00185	1.05594E-07
7	7	8	11.22	0.00201	2.57445E-06
8	8	9	7.29	0.00949	7.89744E-06
9	9	10	11.22	0.00201	2.57445E-06
10	10	11	0.5	0.00185	1.05594E-07
11	11	12	11.22	0.00201	2.57445E-06
12	12	13	0.5	0.00185	1.05594E-07
13	13	14	10.5	0.00141	1.69007E-06
14	14	15	7.29	0.00949	7.89744E-06
15	15	16	0.5	0.00185	1.05594E-07
16	16	17	10.5	0.00141	1.69007E-06
17	17	18	8	4.02E-03	3.67122E-06
18	18	19	10.5	0.00141	1.69007E-06
19	19	20	0.5	0.00185	1.05594E-07
20	20	21	7.29	0.00949	7.89744E-06
21	21	22	10.5	0.00141	1.69007E-06
22	22	23	6	0.00021	1.43836E-07
23	23	24	10.5	0.00141	1.69007E-06
24	24	25	2.4	0.0017	4.65753E-07
25	25	26	10.5	0.00141	1.69007E-06
26	26	27	5.8	0.0052	3.44291E-06
27	27	28	10.5	0.00141	1.69007E-06

28	28	29	8	0.00022	2.00913E-07
29	29	30	10.5	0.00141	1.69007E-06
GEN1	---	1	1.32	1.96	0.000295255
GEN2	---	31	25.7	0.58269	0.001706573

The original program flowchart is indicated in Figure 7 for simulation by the Monte Carlo method.

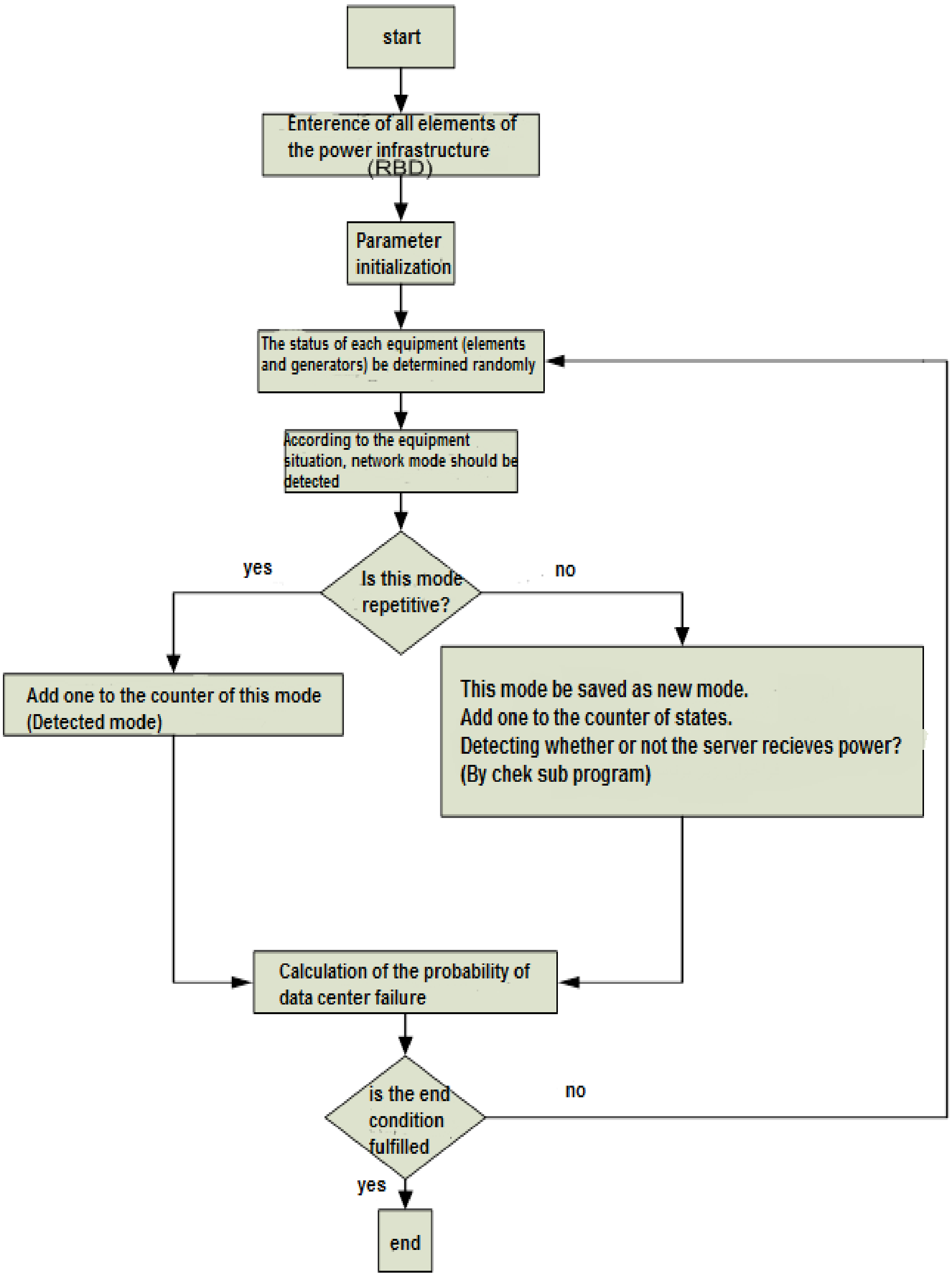


Figure 7-the Main Program Flowchart of Monte Carlo Method Simulation

In this program, the RBD program called all information elements of the data center power infrastructure into two sub-programs according to Table 3- Each data centertier had its own RBD table- Then throughusing it, the initial parameters were identified as the number of elements, nodes and generators. In the next step, considering the probability of failure of each element, its status was determined randomly, that zero state is the failure and one is considered the healthy state of each element. (The lower the likelihood of a single element failure, the lower the likelihood to be assigned in determined repetitions as in failure state). The values of the elements were considered for shaping the structure of the power infrastructure network. The status of delivering power to the rack including the IT equipments, was determined through using the CHEK program.The number 1 indicates the delivery of the power and the zero number represents the serviceoutage.This structure cannot be re-checked in the subsequent replicates, in a time that the same structure is formed, because it has already been stored.The power supply infrastructure of the data center was obtained by dividing the number of states in which the output is one, by the total number of states.

3. Investigation ofElectromagnetic Protection Effect on the Failure Rate of Elements

First, from the IEEE 493, 2007 Gold Book the reasons for the failure of each element were derived, in order to examine the influences of electromagnetic protection on the failure rate of the elements forming the power infrastructure of a data center. Failure-trigger is caused by somewhat similar reasons as electromagnetic threats (like lightning), and the causes are limited or eliminated by the application of electromagnetic protection. Therefore, for electromagnetic protection, based on the type of any reason, a coefficient of recovery is estimated.The statistics of electromagnetic protection in 15 data centers is considered in determining these coefficients.

1.3. The Causes of Failure-trigger in the Elements of Data Center Power Infrastructure

In general, for the delivery of electricity or power from a public distribution source or diesel generator to a rack including the IT equipment, several elements are being used, which include: Cable, Manual/Automatic Disconnect Switch, Fuse, Transformer, Circuit Breaker, SwitchGear, Uninterruptible Power Supply (UPS) and Power Distribution Unit (PDU).

The number and method of placing each of the above elements are determined based on the variable data center tier.

Based on the statistical surveys, most of the reasons for the failure-trigger of the elements that make up the power infrastructure of the data centers are as follows [11]:

Power disturbance - High temperature - Loss of winding insulation - Loss of bush insulation (shell) and other winding insulations - Mechanical fracture - Cracking, loosening, wearing, mechanical burning - Mechanical damage from external sources (drilling , Car crash, etc.) - Short circuit by metal devices - Short circuit by birds, snakes and other animals - Bad operation of the protective relay of the control device - Inappropriate operating method - loosening of connections and terminals - Low voltage – Increase of continuous voltage - Frequency Low, and so on. The extent of the influence of each of these causes on failure of each element is different.

The overall rate of the effect of each element on the failure is achieved by summing up the effect of electromagnetic protection on any of the root causes considering their effectiveness. For example, in Table 3.1, the effect of electromagnetic protection is assessed considering the reasons of the failure-trigger of power transformers.

Table 4- The effect of Electromagnetic Protection on the Causes of Power Transformers Failure

The cause of the failure trigger	**Power Transformers**	**Improvement coefficient due to electromagnetic protection**	**Power Transformers (after Protection)**
	percent		**percent**
Power failure	16.4	0.9	1.64
High temperature	2.7	0	0
Loss of winding insulation	29.1	0.5	14.55
Loss of bush insulation (shell)	13.6	0.3	9.52
Loss of other insulations	5.5	0.5	2.75
Mechanical fracture, Cracking, loosening	7.3	0.3	5.11
wearing, mechanical burning	2.7	0	0
Mechanical damage from external sources (drilling, Car crash, etc.)	2.7	0	0
Short circuit by metal devices	0.9	0	0
Short circuit by birds, snakes and other animals	2.7	0	0
- Bad operation of the protective relay of the control device	4.6	0.6	1.84
Inappropriate operating method	3.6	0	0
- loosening of connections and terminals	7.3	0	0
others	0.9	0	0
total	100	0	35.41

According to Table 4, the failure rate of power transformers is decreased by about 65% through electromagnetic protection .This is because of the reduction of the causes of the failure-triggerof this element due to protection. As demonstrated in the table above, the effect of electromagnetic protection on many of the root causes is zero and on the other is up to 90%; these coefficients are derived from data collected from 15 data centers under electromagnetic protection according to the statistics.

Powerdisturbance is one of the most effective reasons for the failure-trigger of most of the elements, which is briefly summarized below:

Powerdisturbances may be as follows:

- Sudden increase in voltage (Surge)
- Reduced Voltage (Sag)
- An electrical signal with high scope and a little time or short-term transient voltage and sharp point (Spike)
- Swell
- Transient
- Fluctuation
- Interruption
- Electric Line Noise

Almost 70% of the electrical threats are toward inside of the centers, which are generated by the passes, power line noise, interruptions, delays, electrostatic discharge, and sudden voltage drop.The remaining 30 percent can be due to changes in the publicpower lines that are triggered by the lightning, high or low voltages, swells and sags.

In fact, may be the most destructive of the high voltage transient is the lightning strike. A direct strike can deliver thousands of volt amperes to the line.Through interference inductance, any conductor circuit within a few kilometers of a lightning strike can experience a transient voltage of thousands of volts and pass through vulnerable electrical equipment panels against a sudden increase in voltage.

Transient disturbances can be divided into two parts from other perspectives:

1- Impulse: High voltage and current in low time. Like a lightning strike
2- Fluctuation: Lower voltage and current in a longer time period (greater than 50 times the time of lightning strike). Such as photocopiers, controlled equipment and induction load switching.

80% of the instantaneous voltages transient are produced from domestic sources and up to 20% of them are produced from foreign sources. Some other factors that cause powerdisturbances include:Elevators, air-conditioning equipment, Electric arc welding, personal computers and telephone systems [17]

2.3. Protection Methods

Electromagnetic Threats are an electromagnetic pulse with an electric field of more than 50 kV / m and a frequency range of between kHz and 15 GHz for miscellaneousweapons, including nuclear explosions.At frequencies above 15 GHz, it's difficult to generate high destructive power and the release of high-frequency waves in the atmosphere is also accompanied by a high drop. Different protection methods are used for sensitive equipment, which requires protection from these threats [9]. These methods include:

- Air filters and air conditioning system
- Electromagnetic seals
- Shielding the building
- Ground to the impeller well
- Power filters
- Electromagnetic Threat Warning Sensors
- Electromagnetic shielding boxes
- Flexible protective tents
- Protective bags of carrying out electronic and telecommunication equipment

In electromagnetic protection in order to protect electrical equipment against a range of threats, special filters are used along the way to the input cables to the building as well as before the server rack inputs. It also avoids emitting any electromagnetic wave into the data center building by implementing arrangements such as shielding, seals, air filters, and air conditioning.This leads to eliminating a high percentage of powerdisturbances before entering the building and even being removed by internal filters if they enter. Also, power disturbances produced within the data centers accounting for a high percentage of all disturbances (above 80%) are eliminated by EMP, EMC, and EMI filters. Therefore, according to available sources, the effect of electromagnetic protection on powerdisturbances is about 90%, i.e. a high percentage of these disturbances are eliminated through electromagnetic protection.

In Table 5, the effects of electromagnetic protection on the main elements of the data center infrastructure are calculated. The background information of this table is taken from the IEEE 493 2007 Gold Book Standard.

Table 5- The Effect of Electromagnetic Protection on the Failure Rate of the Element Components of Power Infrastructure

REF #	ITEM DESCRIPTION	Failure rate failure/year	electromagnetic protection effect percentage	Failure rate failure/year After protection
1	Single Circuit Utility Supply, 1,78 failures/unit	1.956	47	0.91932
2	Cable aerial, ≤ 15kV, per mile	0.04717	50.6	0.02386802
3	Diesel engine generator,packaged, standby, 1500 kW	0.58269	43.7	0.25463553
4	Manual disconnect switch	0.00174	35.2	0.00061248
5	Fuse, 15 kV	0.10154	59.3	0.4132678
6	Cable belowground in conduit,≤ 600 V, per 1000 ft	0.00201	50.6	0.00101706
7	Transformer, liquid, nonforced air, 3000 kVA	0.00111	64.59	0.000716949
8	Circuit breaker, 600 V, drawout, normally open,> 600 A	0.00553	59.3	0.00327929
9	Circuit breaker, 600 V,drawout, normally closed,> 600 A	0.000925	59.3	0.000548525
10	Switchgear, bare bus, 600 V	0.00949	28.9	0.00274261
11	Circuit breaker, 600 V drawout, normally closed, < 600 A	0.00021	59.3	0.00012453
12	Circuit breaker, 600 V,normally closed, > 600 A	0.0096	59.3	0.0056928
13	Circuit breaker, 3-phasefixed, normally closed,≤ 600 A	0.0052	59.3	0.0030836
16	Cable, aboveground, trays,≤ 600 V, per 1000 ft	0.00141	50.6	0.00071346
22	Switchgear, insulated bus,≤ 600 V	0.0017	50	0.00085
60	Cable, above ground,No Conduit, ≤ 600 V, per 1000 ft	0.000096	50.6	0.000048576
ups	ups	0.00402	65	0.002613
Pdu	Pdu	7.36088E-06	64.59	4.75439E-06

The effectsof electromagnetic protection are constant on any of the reasons for the failure-trigger of the elements, but the effect valuesof the failure-triggered causes are different based on the failure rate of each element. For this reason, the effects of electromagnetic protection on the failure rate of different elements also vary, as indicated in Table 5.

In Figure 8, the improvement coefficient of the electromagnetic protection effect on the failure rate of each element is demonstrated. The higher the coefficient, the lower the failure rate of the element.Also, the decreasing coefficient of failure rate is mentioned which is the opposite of the recovery coefficient. The lower this coefficient, the lower the failure rate of the element is.

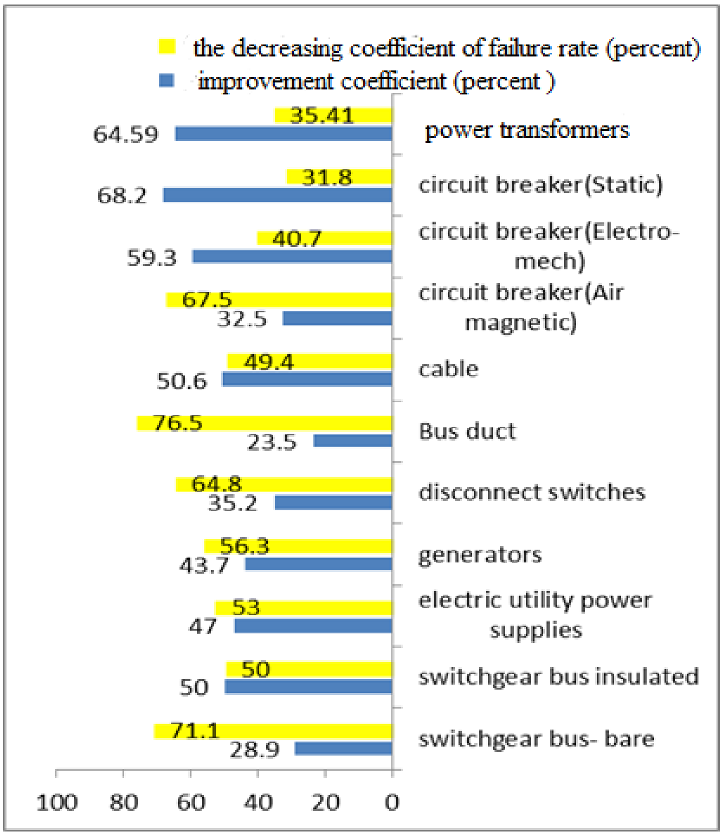


Figure 8- The Electromagnetic Protection Effect on the Failure Rate of the Elements Forming the Power Infrastructure

The static circuit breakers, receive the greatest effects of the application of electromagnetic protection among the elements that constitute the power infrastructure of a data center. That is, the failure rate of static circuit breakers decreases dramatically (68.2%) due to protection.

4. The Electromagnetic Protection Effect on the Reliability of Data Centers

In the previous section, the effect of electromagnetic protection on each element of the power infrastructure of the data centers was calculated.

Theprobability of failure of the elements varies due to the effect of electromagnetic protection on the failure rate of the elements.The likelihood of failure of each element depends on two parameters of the failure rate and the MTTR.Since the MTTR of the elements has been considered before and after the constant protection; the probability of failure is only affected by the failure rate of each element, which should be measured again.

The new parameters which change the table under the existing sub-program in the simulation process are called RBD.

The Reliability Block Diagram of the data center infrastructure and the sub-program of checking before and after the electromagnetic protection was constant, therefore the reliability of the power infrastructure of different data centers after electromagnetic protection was only affected by the change in the RBD sub-program, which would be different from its amount before the protection.

That is, by inserting a new RBD sub-program in the simulation program, the reliability of the power infrastructure of the data centers in the tiers 1 and 2 is obtained after the electromagnetic protection.In Table 6 and 7, the results of the Monte Carlo simulation are indicated on the reliability block diagram of the data centers of the tiers 1 and 2.

Table 6- Results obtained from Monte Carlo Simulation on the Reliability BlockDiagram of Data Center in Tier 1

Number of random tests	Reliability		The amount of outage (In minutes)	
	without protection	with protection	without protection	with protection
10,000,000 times	0.9999530	0.9999806	1065.791	671.598

Table 7- The results obtained from the Monte Carlo Simulation on the Reliability Block Diagramof Data Center in Tier 2

Number of random tests	Reliability		The amount of outage (In minutes)	
	without protection	with protection	without protection	with protection
10,000,000 times	0.9999614	0.9999859	701.825	307.230

5. Calculation of the Saved Cost via Electromagnetic Protection Effect

In order to calculate the saving cost via electromagnetic protection effect of data centers in tier 1 and 2, the cost of implementing protection for these two centers was initially calculated. Based on the data gathered as well as the situation in different regions, the average electromagnetic protection implementation for a middle class data center is about $ 80,000 for 10 years and for the middle-class data center is about $ 120,000 for 10 years. As a result, the annual cost of the electromagnetic protection of the middle class data center in tier 1 is $ 8,000 and for the data center of the tier 2, itis $ 12,000.

Considering the information given in [16], the cost of outrage of tier 1 data center is about $ 93 per minute, and the tier 2 data center is $ 356 per minute.

The outrage rate of a data center of a tier 1 per year according to the above table is about 1065 minutes, by multiplying this number at anoutrage cost per minute, the annual cost is $ 99045. If the electromagnetic protection measures are implemented on this data center, its annual outrage will be reduced to about 671 minutes.With a 394-minute reduction in outrage in a year, the cost savings, including the cost of implementing electromagnetic protection ($ 8,000 per year), are $ 28,642 per year.

In the case of the data center of the tier 2 after passing the mentioned stages, the annual cost savings achieved through the electromagnetic protection is$128620 (Table 8).

Table 8- The Amount of Saved Cost per Year due to Electromagnetic Protection

Data center tier	the outrage cost per minute (dollars)	Annual outrage decrease rate (min)	Cost savings per year (dollars)
tier 1	93	394	28642
tier 2	356	395	128620

6. Conclusion

According to the results of Table 4.3, the electromagnetic protection of data centers, in addition to preventing vulnerability to electromagnetic threats, also decreases their annual outrage cost. Providing these statistics and tables can help senior executives make the best decisions on the implementation of electromagnetic protection in data centers.These results can also be generalized to many of the country's command and control centers, since many of them have infrastructure that is almost similar to the power infrastructure of data centers.

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