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**6**

LIN C Y J E M IN A K K U LN A T H S , G O W T H A M V \*

S , G O

lin c yya b e z@ g m a il.c o m , g o k k u ln ath 9 1 2 0 @ g m a il.co m , g o w th a m ve n k a te s a n 4 @ g m a il.co m ,

D e p a rtm e n t o f C S E , P a n im a la r E n g in e erin g C o lle g e , C h en n a i, In d ia

\*C o rres p o n d in g A u tho r E m a il:g o k k u ln a th 9 1 2 0 @ g m a il.co m

: T h e q u ic k ris e o f elec tric b us e s in p ub lic tra ns p o rt b rin g s n ew c h allen g e s in h o w th ey a re ch a rg ed , h o w t he ir b a t teries a re m a n a g ed , a n d h o w effic ien tly t h ey o p erat e.T h is p a p er in tro d u ce s a co m b in ed s ys t em fo r o p tim iz in g e lect ric b u s e s an d t he ir ch a rg in g p ro ce s s es . It inc lud es b a tt ery s w a p p in g , s m a rt c ha rg ing s tra teg ie s , a n d in te llig e nt s c he d u lin g a n d ro u tin g o f b u s es . Th e g o al is to cu t d o w n o n ve hic le d o w n tim e, lo w er o p era t in g e xp e n s es , a n d k ee p s ervice s relia b le b y c ha rg ing d uring les s b u s y t im es , m a k in g t h e b es t u s e o f d e p o ts , a n d m a na g in g en erg y in rea l t im e. Th e s im u lat io n re s u lt s s ho w b e tte r p e rfo rm an c e o f t h e b u s flee t, c o s t red u ct io n s , a nd m o re s u s ta in a b le en erg y u s e, s h o w ing h o w s m a rt p lan n in g ca n c h an g e ho w c it ies m o v e p e o p le.



**4**



**8**

K e yw o rd s : E V b u s , ch a rg in g o p t im iza tio n , b a tt ery s w ap p ing , b u s s c he d u lin g , ro ut ing , e ne rg y

m a n a g em e n t, p ub lic t ra n s p o rta tio n , o p erat io n al efficien c y.

# I.INTRODUCTION

T he m o ve to w a rd s u s ta in ab le tra n s p o rta tio n h as led t o a fa s ter g ro w th in t he us e o f e le ct ric ve h ic les , es p ecia lly in p u b lic tra ns p o rt .E lec tric b us e s are b e co m in g m o re co m m o n a s t h ey p ro d u ce le s s p o llu t io n, r, a n d o ffe r lo ng -te in g a lo t o f e le ct ric b u s es b rin g s u p s o m e k ey

a re q u iet e

rm co s t s a v in g s . H o w ev er, u s



**1**



**1**

**7**

ch a llen g es , s u ch as lim ite d d riv in g ran g e , lo n g e r ch a rg in g tim e s , e xp e n s iv e in fra s truc tu re , a n d m a n ag in g a la rg e fle et effic ien tly.U s in g t ra d itio n a l p lu g -in ch a rg in g c a n c a us e b u s es to s it id le fo r lo ng p erio d s , in cre a s e elec tric ity u s e d u rin g b u s y tim e s , a n d n o t u s e th e b us e s to th e ir fu ll p o te n tia l.

T o s o lv e th es e p ro b lem s , n ew m et ho d s lik e b at te ry s w a p p in g , s m art ch a rg in g , a n d b e tte r b u s s ch e d u lin g a n d ro ut ing ha v e b e en d e ve lo p ed . B a tt ery s w a p p in g h elp s b y q u ick ly re p la cin g a b u s ’ s u s ed b at te ry w ith a ch a rg e d o n e, re d u cin g w a it ing t im e. S m a rt ch a rg in g d u rin g o ff-p ea k h o u rs lo w ers en e rg y b ills an d les s e n s p res s u re o n th e p o w e r g rid . W h en co m b ine d w it h flex ib le s ch e d u lin g a n d s m a rt trip p la n nin g , t he s e m eth o d s b o o s t th e efficien c y o f t he b u s flee t, m a k e p u b lic t ra n s p o rt m o re relia b le, a n d s up p o rt a m o re s u s ta in a b le o p e ra tio n .

T his p ro jec t is a b o u t crea tin g a co m p lete s y s tem fo r o p t im izin g e lect ric b u s es a nd t he ir c h arg in g .B y

u s ing ad va n ce d s ch e d u lin g t o o ls , rea l-t im e en e rg y c o n tro l, a n d s m a rt o p era t io ns a t d ep o ts , th e s y s tem is d es ig n ed to b e m o re c o s t-e ffe ct iv e, red uc e d o w n tim e , a n d o ffe r b et ter s e rv ice. T h is a p p ro a ch c a n b e a us e ful ex a m p le fo r c ities lo o k in g to s w itc h t o clea n er, m o re efficien t , a n d fu t ure-rea d y t ra n s p o rt a tio n .

# LITERATURE REVIEW

1 . O p tim iz a tio n Fra m ew o rk s fo r Sc he d u lin g a n d R o u tin g

A lo t o f res ea rch is fo cu s ed o n crea tin g s tro n g a n d efficien t m e th o d s to s o lv e th e ele ctric b u s s ch e d u lin g p ro b le m .T h e m ain c h allen g e is a d a p t in g t he t ra d itio n a l v eh icle s ch ed u lin g p ro b lem to in clu d e t hin g s lik e lim ited b a tte ry ra ng e, ch a rg in g tim e , a n d th e av a ila b ility o f c ha rg ing s ta t io ns . M ixe d -In te g er Lin ea r P ro g ram m ing (M ILP ) is a c o m m o n a p p ro a ch u s e d t o b u ild m o d els t ha t a im to re d u ce t h e n um b er o f b u s e s n e ed e d an d lo w er o p era tin g co s t s .

R es e a rch e rs us e M ILP to o p tim ize ro u tes fo r ele ctric v eh icle s , re d u ce trav el tim e , m a n ag e c h arg in g a t s ta t io ns w it h m u ltip le p o rt s to a vo id d e la ys , a n d s c h ed u le ch a rg in g b a s e d o n t im e-o f-us e e le ct ricity p ric es to s a v e m o n ey . W h ile M ILP w o rk s w ell fo r s im p le r p ro b lem s , it ca n b e s lo w a n d co m p u ta tio n a lly h ea v y w h e n d e a lin g w ith la rg e, rea l-w o rld s y s tem s .

T o o ve rc o m e t he s e ch a llen g es , re s ea rc he rs u s e te ch n iq u es lik e d ec o m p o s it io n a n d h eu ris tic s .

F o r e xa m p le , c o lum n g en erat io n is a m et h o d th a t s p lits a b ig p ro b lem in to s m a lle r p a rt s — a m as t er p ro b lem an d a s ub p ro b le m — m a k in g th e p ro ces s m o re efficien t, e s p ec ia lly fo r larg er fleet s . A ls o ,

m e ta h eu ris tic m et h o d s s u ch a s Sim u la ted A nn e alin g (S A) a n d G en e tic A lg o rith m s (G A ) are u s e d to ta c k le co m p lex a nd larg e-s ca re h a rd t o s o lv e w ith t ra d itio n a l m et ho d s . A s t ud y o n th e tra ns it s ys te m in L ux em b o u rg s h o w ed t h at th e s e m eta h eu ris t ics w o rk ju s t a s w ell a s M IL P fo r s m a ller p ro b lem s , b u t th e y are m u ch b e tte r fo r s c alin g u p .

le p ro b lem s th a t a



**3**

A n o th er t re nd is m o v in g to w a rd rea l-tim e , d a ta -d rive n s o lu tio n s to h an d le t he c o n s ta n tly ch a n g ing co nd it io n s in o p erat io n s .So m e s tu d ies s u g g e s t u s in g M a rk o v D ecis io n P ro ces s e s a n d H iera rch ica l D ee p R e in fo rcem en t Lea rnin g (D R L ) to a cc o u nt fo r u n p re d icta b le fa cto rs lik e w ea th e r a n d tra ffic, w h ic h ca n im p a ct th e b a tt ery's c h arg e lev el an d h o w lo n g it t a k es fo r b us e s t o a rrive . An ex p erim en ta l s y s tem b a s ed o n M a rk o v D ec is io n P ro ce s s es red uc ed ch a rg in g co s t s b y 2 3 . 7 % a nd ele ctricity u s e b y 1 2 .8 % u s ing a c tu a l d a t a fro m a b u s fleet in S he n zh en , Ch in a .

1. .Int eg ra tio n o f S u s ta in ab le E n erg y an d G rid R es ilien ce

T he res ea rch h ig h lig ht s t ha t a s u s ta in a b le e lect ric b u s flee t ca n 't o p era te ind ep e nd en tly fro m it s e ne rg y s o u rc e.T h e in c o rp o ra tio n o f re n ew a b le e n erg y s y s tem s a n d b a t tery s to rag e is a k ey fo cu s . H yb rid m icro g rid s a re a p o p u la r s o lu tio n , a s t he y c o m b in e s o lar p h o t o v o lta ic (P V ) s ys t em s a nd h yb rid P V -w ind s et u p s to re d u ce relia nc e o n th e m a in p o w er g rid a nd im p ro v e en v iro n m e nt a l s u s ta in a b ilit y.



**11**

A ca s e s tu d y at S ta n fo rd U n ive rs ity 's b u s d e p o t s h o w ed t h at u s ing o n -s ite s o la r e ne rg y a nd b a tt ery s to ra g e c o u ld s a ve aro u n d $ 3 .7 m illio n a n d cu t e m is s io ns b y 9 8 % o ve r a 1 0 -yea r p erio d .A no th er p ro m is ing a rea is t he co n ce p t o f u s ing e lect ric b u s e s a s m o b ile e n erg y as s e ts .

T hro u g h b id irect io n al c h arg in g , elec tric b u s es ca n s u p p ly p o w er to b u ild in g s d u rin g e m erg en cie s o r s en d en erg y b a ck to t he g rid to m an a g e h ig h d em a n d . P ilo t p ro je ct s , lik e o ne b y B C H yd ro u s in g elec tric s ch o o l b us e s , are e xp lo ring h o w V eh icle -to -G rid (V 2 G ) tec h no lo g y ca n im p ro v e g rid relia b ilit y a n d o ffer b a ck u p p o w e r d u rin g o u ta g e s , red u cin g th e n e ed fo r d ie s el g en era to rs . A p ro je ct in O k la h o m a a ls o u s e d a fle et o f ele ctric s ch o o l b u s es t o p ro v id e e m erg en cy p o w er a fte r a t o rn a d o .

1. .C o m p a rin g B a tt ery C h a rg in g a n d Sw a p p in g E co no m ics

T he litera tu re a ls o co m p a res d iffe ren t w ay s to rec ha rg e e lect ric b u s es , em p ha s iz in g th e t ra d e -o ffs b e tw ee n c o s t a n d o p era t io na l efficien c y.D ep o t o r o ve rn ig h t ch a rg in g is t he m o s t co m m o n m e th o d .B u s es a re c h arg ed a t t h e d ep o t b e tw ee n t rip s . T h is a p p ro a ch is ea s y to im p le m en t b ut ca n re q u ire a larg er fle et a n d m a y p u t a lo t o f s tre s s o n t h e elec tric ity g rid d uring p ea k tim es .

O p p o rtu n it y o r o n -ro u te fa s t c ha rg ing in v o lve s s h o rt, freq u e nt ch a rg e s a t t erm ina ls o r a lo n g th e w a y.T h is m e th o d req u ire s m o re in fra s t ru ct ure, b u t it c a n allo w fo r s m a ller b a tte ries a nd is b e tte r fo r b a t tery life, a s fre q u en t s h a llo w ch a rg e s a re g e n tler o n th e b a tte ry th a n d e ep ch a rg e s .B a t tery s w a p p in g is a n a ltern at ive t h at in v o lve s rep la c in g t he b a tte ry p a c k q uic k ly , w h ic h s ig n ifica n tly re d u ces d o w n t im e.

T his is es p ecia lly u s efu l fo r h ig h -u s e co m m erc ial fle et s w h ere d e lay s a re c o s tly. Sw a p p in g s ta tio n s ca n a ls o d o u b le as e n erg y s to ra g e s y s tem s to h e lp b a la n ce th e g rid . H o w e ve r, a m a jo r ch a lle n g e is t he n eed fo r s ta n d a rd iz ed b a tt ery p a ck s fro m d iffe re nt m a n u fac tu re rs t o m ak e t his m et ho d s c ala b le a nd co s t-e ffe ctiv e. Th e "B at te ry-a s -a -S ervic e" (B a aS ) m o d el, w hic h s ep a ra t es b a t tery c o s ts fro m v eh icle p ric es , ca n red u c e u p fro n t c o s ts a n d g ive m o re flex ib ilit y to v eh icle o w n ers .

1. .P ra ct ica l C o n s id e ra tio n s a nd R e a l-W o rld Ch a llen g es

R es e a rch c o n s is t en tly p o in t s o u t th e g a p b et w e en th e o re tica l m o d e ls an d rea l-w o rld a p p lica t io ns . B a t tery d eg ra d a tio n is a k ey c o s t fa ct o r o fte n ig n o red in s tu d ies .

O ne s t u d y fo un d th a t b a tt ery w e ar a n d te ar c a n c o s t a b o u t 8 7 .2 6 % o f t o ta l o p era tin g c o s ts , m a k in g it a b ig g e r ex p e ns e t h an ch a rg in g its e lf. M a n a g in g t h e b a tt ery 's c h arg e lev els re g u la rly is es s e n tia l to re d u ce t h is w ea r.

T he b e s t s trat eg y fo r a n elec tric b us fle et d e p en d s o n lo c al co n d itio n s , s u ch a s ele ctricity p ric es , g o v ern m en t p o lic ie s , a n d th e s p e cific lay o u t o f a c it y’ s tran s it s ys t em .

F o r ins t a nc e, a m a jo r p ro jec t in In d ia a im e d to ex p a n d t h e u s e o f ele ctric b us e s fo u n d t ha t g ro u p ing d e m a nd an d c re at ing un ifo rm s p ec ifica t io ns c o u ld lea d t o lo w er p rice s th a n d ie s el o r CN G b u s es . H o w ev er, it a ls o h ig h lig h ted c ha llen g e s lik e fin a n cin g , t ec hn ica l ex p ertis e, a n d th e d ifficu lty o f a d a p t ing to d ifferen t lo c al s itu a tio n s .

# EXISTING SYSTEM

M a n y s tu d ies rely o n s im p lified o r s ta tic a s s u m p t io n s , w h ich lim it h o w u s efu l t h eir find in g s a re in th e re a l w o rld .T h e la c k o f rea l-w o rld d a ta is a m a jo r lim ita t io n in th e lit erat u re, s h o w in g t h e n e ed fo r m o re re s ea rc h th a t c a n h a n d le d yn am ic a n d u n certa in co n d itio n s , a n d b rid g e t h e g a p b etw e en s im u lat io n s a n d a c tu a l p ra ctic e.M o s t elec tric b us s ys t em s to d a y u s e t ra d itio n a l c h arg in g m eth o d s a n d fix ed s ch e d u le s . B u s e s u s ua lly fo llo w s et ro u te s a nd tim e ta b les , a nd th ey ch a rg e th eir b at te ries o ve rn ig h t o r a t th e d ep o t . W h ile th is s et up is ea s y t o m a na g e , it c o m es w ith s ev eral is s u es :

Lo ng C h a rg in g T im es : W h e n b u s e s a re p lu g g ed in d u rin g th e ir la yo ve rs , it c a n t a k e s ev eral h o u rs to

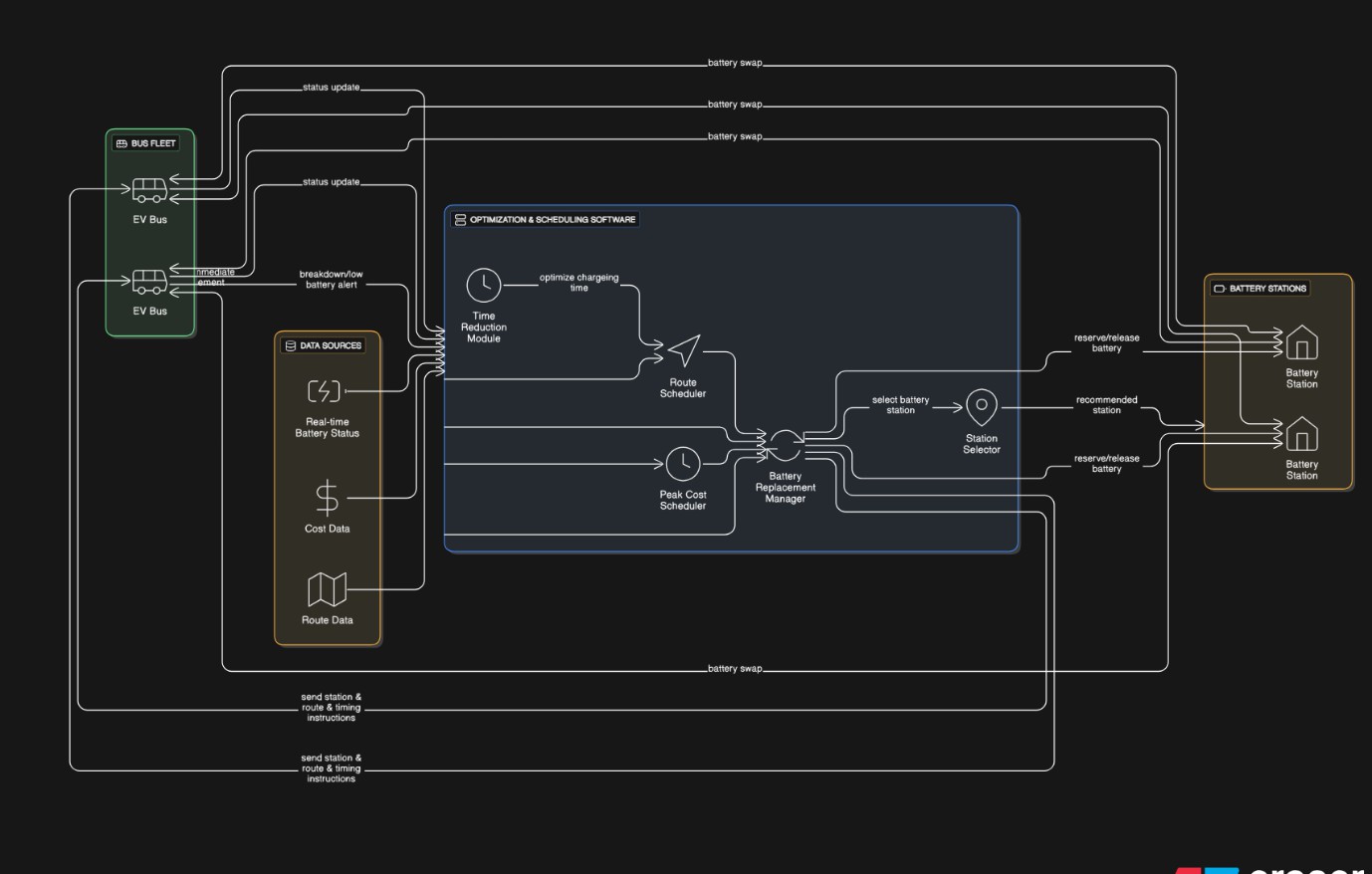
ch a rg e fu lly. T his re d u ces h o w m an y b u s e s a re a v a ila b le fo r u s e a n d in crea s es t he t im e th ey a re o u t o f s ervic e. H ig h E n erg y Co s ts Du rin g P ea k H o u rs : If c h arg in g is n 't p lan n ed w e ll, it o ft en h ap p en s w he n ele ctricity d em a n d is h ig h es t .Th is lea d s to m o re ex p en s iv e p o w e r b ills a n d p u ts ex tra s t ra in o n th e lo ca l p o w e r g rid . Lim ite d Co nn e ctio n B e tw ee n C h a rg in g a n d Sc he d u lin g : B u s ro u t es a nd s c h ed u les a re u s u ally p la n n ed w ith o u t ta k in g int o a cc o u n t h o w m u ch b a t tery e ac h b u s h as le ft , w h e re th e c ha rg ing s ta t io ns a re , o r th e cu rren t s t a te o f th e p o w er g rid .

N o B a tt ery S w ap p ing A v aila b le: M o s t s ys te m s d o n 't u s e b a tte ry s w a p p in g , w hic h co uld cu t d o w n o n

w a it ing tim es s ig n ific a nt ly.Lim it ed E m erg en cy P re p a red ne s s : Cu rren t s y s tem s aren 't w e ll p rep a red fo r em erg en cies lik e p o w er o u ta g es , n a tu ra l d is a s te rs , o r s u d d en ch a n g es t o b u s ro ut es .In m o s t c a s es , p la n nin g th e ch a rg in g infras t ru ct u re a n d s ch e d u lin g t he b u s es a re h a n d led s e p a ra te ly. Th is lea d s to w a s ted res o urce s , les s reliab le s ervice , a n d h ig h er c o s ts . S o m e n ew er s y s tem s are s t artin g to u s e s im p le s m a rt-c ha rg ing fe a tu re s , b u t t h ey s till d o n 't fu lly co n n ec t ch a rg in g o p tim iza t io n, b u s s ch ed ulin g , b a tt ery s w a p p in g , a nd e m erg en c y res p o n s e p la ns .

# PROPOSED SYSTEM

## A .S Y S TE M A RC H IT EC TU R E



B . M O D U LE D E S C R IP T IO N

T he s ys te m d es ig n e d fo r o p t im iz in g elec tric ve hic le b u s es a nd t h eir c ha rg ing is m a d e up o f s e ve ra l m a in p arts .E ac h p art h a nd le s a s p e cific ta s k , a n d to g et he r th e y fo rm a co m p le te s y s tem .

1. .U s e r / Fle et M a n a g em en t M o d ule

T his p a rt d ea ls w ith s ig n in g u p b u s es , k eep in g tra ck o f t h eir ro ut es , b at te ry d e ta ils , a nd a s s ig n ing d riv ers t o v eh icles . It a ls o o ffers d a s h b o a rd s th a t let u s ers w a tch th e s ta tu s o f b u s es , h o w w e ll th eir b a tt erie s are d o in g , an d w h ere th e b u s e s a re d u rin g trip s in re al tim e .

1. .C h a rg in g O p tim iz at io n M o d u le

T his m o d u le fig ures o u t th e b e s t tim e s to c h arg e b us e s b a s ed o n h o w m u c h it c o s ts a t d iffe ren t tim e s , h o w m u ch p o w er t h e g rid ca n h an d le , a nd h o w m u ch ch a rg e th e b a tt erie s h a v e.It g ive s p rio rity to c h arg in g d u rin g lo w e r c o s t p erio d s to s a ve m o n ey a nd n o t o ve rlo a d t he p o w e r g rid .It a ls o co nn e cts w ith c ha rg ing s t a tio n s a t d e p o ts a n d p la ce s w h e re b us e s ca n ch a rg e q u ic k ly w he n n ee d ed .

1. .B a tte ry S w ap p ing M an a g e m en t M o d u le

T his m o d ule h a n d les th e p la ce s w h e re b a t teries ca n b e s w ap p ed , inc lud in g t ra ck in g th e n u m b er o f ch a rg ed an d u s ed b at te ries av a ila b le .It d ec id es w h e n a b u s s h o u ld s w a p a b a tte ry ins t ea d o f

ch a rg in g , d e p en d in g o n it s ro u t e a n d b a tt ery lev el.It h elp s k e ep t he b u s es ru n nin g w ith m in im a l

d e la ys a n d k ee p s tra c k o f t he b a tte ry’ s p e rfo rm a nc e a n d ho w it w ea rs d o w n o v er tim e.

1. .B u s S ch e d u lin g & R o u t in g M o d u le

T his p a rt u s es s m a rt to o ls to p la n t he b es t s ch e d u le s , ro ut es , an d h o w v eh icle s a re u s e d .It co m b in es d ec is io n s a b o u t ch a rg in g a nd s w a p p in g to m a k e s u re t he b us e s a re alw a ys av a ila b le fo r s ervic e.It als o c ha n g e s p la n s o n th e fly b a s ed o n traffic a n d ho w m a n y p e o p le a re u s in g th e s e rv ic e.

1. .E m erg en cy & Co nt ing en cy M o d u le

T his m o d u le p rep a re s fo r u n ex p e cte d s it u at io n s b y h a vin g alt ern a tiv e ro u t es , b a c k up c ha rg ing s p o t s , a n d p rio rity b a t tery u s e d u rin g em erg en cies lik e p o w er cu ts , na t ura l d is a s ters , o r ev a cu a tio n s .It s en d s a le rt s a n d h elp s fleet m a na g e rs m a k e q u ick d e cis io n s w h e n t hin g s g o w ro ng .

1. .D a ta A n alyt ics & R ep o rt in g M o d u le

T his p art g a t he rs d at a o n h o w m u ch en e rg y is u s e d , h o w m an y t im es t h e b a tt erie s a re cyc led , a nd h o w reliab le t h e s e rv ice is .It crea te s rep o rts o n c o s ts , h o w efficien t th e s ys t em is , an d h o w ec o -frie nd ly it is , w h ich h elp s in m a k in g b et ter d ec is io ns . It a ls o h elp s p la n fo r e xp a n d in g th e in fra s tru c tu re in th e fu tu re .

**21**

## C .A LG O R IT HM

d ulin g P ro b lem (E B SP ) is a m o re c o m p lica t ed v ers io n o f th e c la s s ic V eh icle

T he E lect ric B us S ch e



**4**

S ch ed u lin g P ro b lem (V S P ), w h ich m ea n s it n eed s a d v a n ced o p tim iz at io n m eth o d s t o s o lve it . Th e m ain ch a llen g e is to red u ce th e n u m b er o f b us e s ne ed e d a nd lo w e r o p e ra tio n a l c o s ts w h ile m a k in g s u re th e b u s es c an ru n w it h o u t ru n n in g o u t o f p o w e r a n d ca n c h arg e a t a v aila b le s ta t io ns . T h e re s ea rc h o n t his to p ic co v ers m a ny d ifferen t m e th o d s , fro m e xa ct m a th em a t ic a l m o d els to m o re flex ib le a nd s c a la b le

te ch n iq u es th a t ca n w o rk in rea l ti

m e w ith d a ta .



**10**

M ix ed -Int eg e r Lin ea r P ro g ra m m in g (M ILP ) is a co m m o n a n d re lia b le m eth o d fo r s o lvin g th e E B SP , es p ecia lly fo r s trat eg ic p la n n ing a n d s m a ller-s ca le p ro b lem s .T h is m eth o d u s e s b o th co n t in u o u s a nd

b in a ry v ariab le s to m o d el th e p ro b lem , a llo w in g fo r p recis e c o n tro l o f t he p o s s ib le s o lu tio n s . T he m a in g o a ls o f th e M IL P m o d els are to red u c e th e n u m b e r o f b u s es n eed ed , lo w e r to ta l e n erg y co s t s b y us in g tim e -b a s ed e lect ricit y p ricin g , an d m in im ize th e d is ta n ce b u s es trav el w ith o u t ca rryin g p a s s en g e rs .

T he d ec is io n v ariab le s in th e m o d el in clu d e b in a ry ch o ic es lik e w h e th er a ce rt ain trip is a s s ig n ed to a

b u s o r a ch a rg e r is us e d a t a s p ecific tim e , a n d co n t in u o u s va ria b le s t h at tra c k h o w m u ch en e rg y a b u s h a s le ft d u rin g it s ro u te .T he re a re a ls o k e y co n s t ra int s th a t en s u re e ve ry t rip is a s s ig n ed t o ex a ctly o n e b u s , t h at th e b a tt ery le ve l o f e ac h b us s t ay s w ith in s afe lim its , a nd t h at th e o v erall ch a rg in g n ee d s at

ea c h d e p o t d o n 't ex ce ed t he p o w er s u p p ly .



**3**

O ne m a jo r b en efit o f M IL P is t h at it ca n fin d th e b e s t p o s s ib le s o lu t io n fo r a g iv en p ro b le m .H o w e ve r, a s th e n u m b e r o f b u s es a n d ro u te s g ro w s , s o lvin g th e p ro b lem c a n t ak e a lo n g tim e . Th a t's w h y o t he r

a p p ro a ch es a re u s e d fo r b ig g e r a nd m o re c o m p le x u rb a n s ys te m s .T o m a k e it ea s ier to h a nd le la rg e

n et w o rk s , res e arch ers ha v e d e ve lo p ed d e co m p o s itio n a nd h e uris tic m e th o d s .C o lu m n G e n era t io n is a n ex a ct m eth o d t h at s p lit s th e p ro b lem in to t w o p arts : th e m a s t er p ro b lem a n d th e s u b p ro b le m . Th e

m a s te r p ro b lem p ic k s t h e b es t s et o f b u s s ch ed ule s , w h ile t h e s u b p ro b lem lo o k s fo r n ew s ch e d u le s th a t ca n im p ro ve t h e o v era ll s o lut io n . Th is is e s p ec ia lly u s efu l fo r la rg e p ro b lem s w h ere o n ly a few o f th e

p o s s ib le s c h ed u les a re im p o rt an t , w h ic h m ak e s th e s o lu tio n m o re efficien t.

W he n e ve n d eco m p o s itio n m e th o d s a re n't en o u g h , m eta h eu ris t ics lik e Sim u la ted A n n ea ling (S A ) a n d G en et ic Alg o rith m s (G A ) a re u s ed .Th e s e m et h o d s fin d g o o d en o u g h s o lu tio n s q u ic k ly, a n d th ey 're es p ecia lly g o o d a t h a n d lin g rea l-w o rld is s u es lik e lim it ed ch a rg in g s t at io n s a n d th e c o s t o f b u s es

tra ve lin g w ith o u t p a s s en g e rs . A s tu d y in Lu xe m b o u rg s ho w e d th a t th e s e m et h o d s w o rk ju s t a s w ell as M IL P fo r s m a ll p ro b le m s a nd a re m u ch b et te r fo r la rg e r o n es .

A ne w t re nd in th is fie ld is u s ing d yn am ic an d a d a p t iv e s ys t em s t ha t c a n res p o n d t o rea l-t im e

ch a n g es . Th es e s ys te m s he lp b rid g e th e g a p b e tw ee n t he o re tica l m o d e ls a n d th e u n p red ict a b le n at u re o f re al-w o rld tra n s it. M e th o d s lik e M a rk o v D ec is io n P ro ce s s es (M D P ) a nd D e ep R ein fo rc em e n t Le arn in g

(D R L) are u s ed t o cre a te s ys t em s t ha t c a n lea rn a n d a d ju s t t o th ing s lik e ran d o m b u s a rriva l tim e s a n d ch a n g in g b a tte ry lev els d u e t o w e a th er o r traffic. A n M D P -b a s e d s ys te m us e d in S h en zh e n, C hin a ,

s h o w ed b ig im p ro v em e nt s b y cu tt ing c h arg in g co s t s b y 2 3 .7 % an d red u cin g ele ctricity u s e b y 1 2 .8 %

th ro u g h b ett er s c h ed u ling t h at rea c ts to rea l-tim e c o n d itio n s a nd c h an g in g ele ctricity p rices .

# RESULTS AND DISCUSSIONS:

IM P LE M E N TA T IO N D E T A ILS :



**2**

T he p ro p o s ed E V B u s a n d C h arg in g O p t im iza tio n S ys te m w a s d ev elo p ed a s a m o d ula r a p p lica t io n t ha t co m b in es c h arg in g o p tim iza t io n, b at te ry s w a p p in g m a n a g em e n t, b u s s c h ed u ling a n d ro u tin g , a nd em erg en cy res p o n s e fe at u res .

T he s ys t em relies o n a c en tral d a t ab as e a n d a n o p tim iz a tio n en g in e b uilt us in g P yth o n o r M A T LA B (o r a n o th er p referre d p la tfo rm ), a lo ng w ith w eb -b a s ed d a s h b o a rd s fo r o p erat o rs to m o n ito r a n d m an a g e o p e ra tio n s . T h e o p tim iz at io n p a rt o f t h e s ys t em u s e s m ixe d -in teg er p ro g ra m m in g a n d h eu ris tic m e th o d s to h a n d le la rg e n u m b e rs o f b u s es a n d rea l-t im e co n d it io ns .

T he s ys te m rec eiv ed th e fo llo w in g d a ta in p u t s :

* D et ails a b o u t ea c h b u s , in c lu d in g its ca p a c it y, b at te ry s ize , a n d cu rren t c ha rg e lev el
* Lo ca tio n s o f d ep o ts a nd c h arg in g s ta tio n s , a lo n g w ith th e ch a rg in g c ap ac ity a t ea c h s ite
* T im e-o f-u s e e lect ricit y p rice s an d t he av a ila b ility o f re n ew a b le en erg y s o u rc es
* D a ily b u s ro ut e s ch e d u le s an d in fo rm a t io n o n p a s s en g e r d e m a nd
* P red e fin e d tem p lat es fo r h a n d lin g e m erg en cy s it ua t io ns

# CONCLUSION

T his p a p e r int ro d uc ed a co m b ine d m et h o d fo r o p t im izin g elec tric b u s a n d ch a rg in g s ys t em s .

It in c lu d e s ch a rg in g s ch e d u le s , b at te ry s w a p p in g , b us p la n n ing , a n d em e rg e n cy p la n n in g a ll in o n e s ys t em . B y m o v in g aw a y fro m s e p a ra te s o lu tio n s t o a c o o rd ina t ed , d a t a-b a s ed s y s tem , th e m eth o d g rea tly red u c es b u s d o w n t im e, lo w e rs c o s ts , a n d m a k es b et ter u s e o f t he b u s fleet . R e s ult s fro m t es t s a n d rea l-w o rld u s e s h o w th a t c ha rg ing d uring lo w -d em a n d tim e s , s w a p p in g b a tte ries a t im p o rta n t s p o ts , a n d m a k in g s m a rt d ec is io ns a b o u t w h en a n d w h e re t o ru n b us e s all h elp m a k e th e s e rv ice m o re reliab le a n d s u s ta in a b le. Inc lud in g a n em e rg e n cy fe at u re m a k es th e s y s tem m o re res ilien t, s o it c an k eep ru n n ing e ve n d uring u n ex p e cte d p ro b lem s .

O v e ra ll, the sy ste m sh ow s tha t m ixing d iffe re nt c h a rgi ng m e tho d s— in c lud ing c ha rg ing a t d e p o ts , d uring s ho rt s top s , a nd thro ug h b a tte ry s w a p pin g— w o rk s be tte r th a n tra d itio na l a p pro a c he s . T his o p en s the w a y fo r m ore d e p en d a b le , c o s t-e ffe c tiv e , a nd e c o-frie nd ly c ity tra ns po rt.

# FUTURE SCOPE

E v e n tho u gh this sy ste m h a s p ro m is ing re su lts , the re a re s till a re a s to i m pro v e a n d tes t in re a l s itu a tion s:P ilo t D ep lo y m e nts: R un b ig fie ld te s ts w ith p ub lic tra ns po rt c o m pa nie s to s e e ho w th e s ys te m w o rk s u nd e r a c tua l o p e ra ting c on d itio ns .

A d v a nc e d P re dic tiv e A na lytic s : U se m a c hine le a rnin g to pre d ic t thing s lik e p a s se ng e r n um b e rs , e ne rg y p ric e s, a n d ba tte ry c o nd itio n, m a k ing d e c isio ns m o re a c cu ra te .

R e ne w a ble Inte gra tio n: C o nne c t c ha rg ing a nd s w a p p ing s ta tio ns w ith s o la r or w ind po w e r a nd

s to ra g e sy ste m s to m a ke thing s g re e ne r a n d le ss re lia nt o n the g rid .

D y na m ic P ric ing & In c e ntiv e s: C re a te fle xib le c h a rgin g p la ns tha t a d just to re a l-tim e e ne rg y p ric e s a n d p ro gra m s tha t e n co u ra ge e n e rg y us e du rin g off -p e a k tim e s .

V e hic le -to -G rid (V 2 G ) A pp lic a tio ns : L oo k in to us ing e le c tric bu se s a s e ne rg y s to ra g e units to he lp the p o w e r g rid d uring tim e s o f h igh d e m a nd o r em erg e nc ie s .

S ta n da rd iza tio n o f S w a p p ing T e c h no log y : H e lp d e v e lo p c om m o n sta n d a rds fo r b a tte rie s , c o nne c to rs , a nd s w a pp ing e q uip m e nt to m a k e it e a sie r fo r m ore p la c e s to a d o p t thi s te c hno lo g y.

R e silie nc e M o d e ling : Im pro v e the e m e rge n cy m o d ule to be tte r h a nd le c o m p le x situa tio n s lik e lo ng -te rm o uta g e s a nd c ity w ide e m e rg e nc y pla ns .



**9**

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**5**

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